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LABORATORY PLASMA PROBE STUDIES

Walter J. Heikkila



Plasma laboratory experiments and data reduction continued during this reporting period. This report summarizes some of the data obtained on electrostatic resonances observed in the plasma generated at The University of Texas at Dallas.

Dr. Rainer Kist* and UTD personnel utilized a UTD developed digital Langmuir probe plus RF probes to study resonances generated in a collisionless laboratory CO_2 -plasma. Laboratory instrumentation, including the Langmuir probe output, were connected to the PDP 11/45 digital computer which automatically recorded and reduced probe data.

The main body of this report is presented in the following two papers written by Dr. Kist.

Appendix A: Plasma Probe Measurements in a Collisionless Laboratory CO_2 -plasma.

Appendix B: Operation of a Digital Langmuir Probe on Line with a PDP 11/45 Digital Computer

*On leave at UTD, sponsored by the European Space Research Organization (ESRO), now European Space Agency (ESA).

Plasma Probe Measurements in a
Collisionless Laboratory CO_2 -Plasma

by Rainer Kist ⁺

This memo describes diagnostic experiments performed in a collisionless plasma using CO_2 as working gas. In particular simultaneous measurements that have been performed by means of Langmuir- and RF-probes are presented. A resonance occurring above the parallel resonance in the frequency characteristic of a two electrode system is interpreted as being due to the resonant excitation of electroacoustic waves. The memo represents a part of the accomplishments achieved in the course of a laboratory plasma investigation at the University of Texas at Dallas (UTD).

⁺ On leave at UTD, sponsored by the European Space Research Organization (ESRO), now European Space Agency (ESA).

Introduction:

Studies with diagnostic probes in laboratory plasmas have several important advantages as compared to space plasma investigations:

- 1) Systematic variation of the parameters involved with the possibility of measuring over large time intervals and of repeating the measurements .
- 2) Extensive testing of the performance of space plasma probes in a plasma environment prior to a space mission.
- 3) systematic investigation of specific plasma phenomena with the aim of improving existing or developing new diagnostic methods.
- 4) Extensive investigation of various phenomena such as plasma wave mode generation and propagation, instable plasma states and nonlinear effects.
- 5) Relatively low cost and short time period needed for realizing a plasma experiment.

The results of such laboratory plasma investigations may provide data for checking on particular theories in plasma physics or have impact upon the understanding in fields like space plasmas (planetary ionospheres, magnetosphere, solar wind etc.) or even (after scaling up the results properly) fusion plasmas.

For the space plasma physicist the laboratory plasma is and will remain a very valuable tool even though in the coming spacelab age the ionosphere itself may be used for particular investigations as a large scale "laboratory" plasma of low density and temperature.

In the piece of work presented here the influence of the electron temperature on the frequency characteristic of the plasma impedance of a two electrode system was investigated. Of particular interest was the resonant excitation of electro-acoustic waves within two RF electrodes for different geometries and plasma conditions.

Experimental System

A stainless steel vacuum chamber, 70 cm long and 50 cm in diameter, has been equipped with a plasma source which uses CO_2 as working gas. A turbomolecular pump together with a copper shroud which was cooled down to liquid nitrogen temperature provided a background vacuum of about 10^{-6} Torr. Fig. 1 shows the source schematically. The general concept was to produce a discharge plasma in a separate volume V_1 (bell jar) and let it expand into the volume V_2 (chamber) through a diaphragm. During operation typical pressure values were 10^{-2} Torr in volume V_1 and 10^{-4} Torr in volume V_2 . In order to control the pressure gradient and the plasma source performance the diaphragm was an iris which could be varied by means of a feedthrough mechanism. A heated tungsten cathode provides primary electrons for the discharge as well as neutralizing electrons for the ions moving from the discharge region into the tank. A paddle proved very useful in baffling high energetic electrons coming from the discharge.

A set of different plasma probes were installed in the tank, in particular

- a) a conventional Langmuir probe (LP)
- b) a retarding potential analyzer (RPA) and
- c) electrode systems for RF impedance measurements.

Fig. 2 shows schematically the arrangement of the plasma source and the probes in the vacuum system. The probes were mounted on movable high vacuum feedthroughs in order to change their position and/or orientation within the tank.

The RF-measurements presented in this memo were performed with a cylindrical and a spherical two-electrode system (E_1, E_2), as shown in Fig. 3. The principle of the RF-measurement is also shown. A swept frequency RF generator provides a signal of constant amplitude within the frequency interval of typically 1 to 25 MHz. The RF-reference voltage U_R at E_1 as well as the test voltage U_T at E_2 are measured and compared as to their complex ratio

$$U_T / U_R = E + jF$$

by means of a network analyzer hp 8407.

The signals provided by the network analyzer are magnitude

$$\alpha = \left| \frac{U_T}{U_R} \right| = \sqrt{E^2 + F^2} \quad \text{in dB}$$

and phase $\phi = \arctan(F/E)$ in degrees. Magnitude and phase together are a measure for the complex plasma impedance $Z = X + jY$ between E_1 and E_2 . In case of the spherical system half spheres were used as E_1 and E_2 . Additional half spheres were operated as guard electrodes in order to reduce the influence of the tank walls.

In Fig. 4 are shown current-voltage characteristics of a spherical (diameter: 10 mm) stainless steel Langmuir probe.

The parameter of this set of curves is the bias voltage U_1 of the plasma source heating circuit. It can be seen that the velocity distribution and temperature T_e of the electrons is markedly influenced by U_1 . In the present case the distribution function is Maxwellian in good approximation for U_1 -values of - 2 V, - 3 V and - 4 V. The corresponding T_e -values are 0.55, 0.53 and 0.52 eV, respectively. For each of these Langmuir curves the magnitude α measured as function of frequency was plotted on a X-Y-recorder. Fig. 5 shows the corresponding set of curves, which reveals the following essential features:

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- a) above the parallel resonance f_p , which is in our case (no magnetic field) equal to the plasma frequency f_N , occurs an additional resonance f_Z , and
- b) f_Z is pronounced most clearly for the case of Maxwellian distribution of the electrons with low electron temperature T_e ($U_1 = - 2$ V, - 3 V, - 4 V).

This resonance f_Z can be understood in terms of electroacoustic waves (also called electron pressure or Landau waves) which are launched by an RF-source above the plasma frequency. Excitation of this electrostatic type of plasma wave, which is damped with increasing frequency by collisionless or Landau damping, is predominantly responsible for the real part of the impedance of an electrode system immersed into a plasma. For a single electrode this real part would decrease monotonically with increasing frequency. For a two electrode system (E_1 , E_2) as used in our experiment, however, a characteristic electrode distance d can be defined (distance between inner and outer cylinder or between two spheres). In this case the electroacoustic wave can produce a standing wave pattern between E_1 and E_2 . This is expected to occur essentially at eigenfrequencies of the system {electrodes-plasma}, for which the wavelength λ_{ea} (or integer multiples of it) matches the distance d .

To check this interpretation we start with the Bohm/Gross (1959) dispersion relation for these plasma waves

$$\omega^2 = \omega_N^2 + (3 K T_e / m_e) \cdot k^2 \quad (1)$$

Here ω is the angular RF-frequency, ω_N the angular plasma frequency, K is Boltzmann's constant, m_e the electron mass and $k = 2\pi/\lambda_{ea}$ the electroacoustic wave number. Equation (1) gives the wavelength λ_{ea} at the resonance frequency $f_Z = \omega_Z/2\pi$:

$$\frac{\lambda_{ea}}{m} = 0.7263 \frac{\sqrt{K T_e / eV}}{\frac{f_N}{MHz} \sqrt{\frac{f_Z^2}{f_N^2} - 1}} \quad (2)$$

Applied to the measurements of Fig. 5 we get the following table 1:

Table 1

U_1/V	T_e/eV	f_Z/f_N	λ_{ea}/mm
- 1	.61	1.40	56
- 2	.55	1.34	54
- 3	.53	1.31	56
- 4	.52	1.30	52
- 5	.65	1.32	54
- 6	.85	1.38	54

The distance of the cylindrical electrodes is $d = 38$ mm. Due to the cylindrical geometry (equation (1) is strictly valid for plane waves), to the ion sheath, and possible inhomogeneous plasma distribution within the electrodes one cannot expect

an absolute agreement between λ_{ea} and d . But we have as an essential result, that the ratio λ_{ea}/d is constant within a few percent for all combinations (f_N , f_Z , T_e) that occur in the set of curves of Fig. 5.

Theoretical work done by Whale (1963), Bateman (1965) and Lin/Mei (1970) shows that excitation of electroacoustic waves is reduced by the presence of an ion sheath. On the other hand collapsing the ion sheath by changing the electrode bias potential to the plasma potential leads to electron absorption so that damping of the electroacoustic wave is to be expected, *too*. Thus varying the electrode DC-potential U_{DC} from negative (ion sheath extended) to positive (ion sheath "collapsed"), a value for U_{DC} should occur for which the resonance at f_Z is best pronounced.

The curves of Fig. 6, where the potential U_{DC}^T of the test electrode E_2 was varied, exhibit exactly this behaviour and thus seem to confirm the interpretation for the f_Z -resonance suggested above.

Measurements with the spherical electrode system also show the resonance $f_Z = f_{Z1}$ as can be seen from Fig. 7. In this case the distance d of the two spheres was varied. In case of the large distance $d = 92.8$ mm a second resonance f_{Z2} above f_{Z1} occurs. These measurements were analyzed on grounds of a theory by Chasseriaux et al. (1972), in which the potential of an oscillating point charge in a warm isotropic plasma is calculated using kinetic plasma theory. The results predict resonances of the potential and hence of the plasma impedance of a spherical system essentially at those frequencies, at which the wavelength λ_{ea} (or integer multiples) equals the distance d between the spheres. As to our experiment we thus have to check, if the measured values for d , f_{Z1} (and f_{Z2}) and f_N lead to the same electron temperature. The result of this analysis is presented in table 2.

Table 2

d/mm	f_{Z1}/f_N	T_e/eV
92.8	1.11	.44
83.8	1.11	.43
74.8	1.14	.45
65.8	1.20	.53

Again the essential result is that all cases lead in fact within a few percent to the same mean temperature $T_e = 46 \text{ eV}$. In case of $d = 65.8 \text{ mm}$ the error in T_e is relatively large due to the larger error in reading the resonance frequency f_Z . The mean value for T_e is indicated by the straight line drawn into the corresponding Langmuir characteristic of Fig. 8. The additional resonance at f_{Z2} leads, applying the theory of Chasseraux et al., to the value $T_e = .61 \text{ eV}$. This value still seems to be reasonable in view of several error sources like reading error for f_{Z2} , deviation of the velocity distribution of the electrons from maxwellian, presence of an ion sheath around the electrodes etc.

The experiments presented here show that a system of two RF-electrodes lead to additional resonances of the impedance characteristic above the plasma frequency which can be understood in terms of resonant excitation of electroacoustic waves.

Systematic and more detailed investigations of the plasma impedance of two electrode systems will be performed in the big plasma chamber at IPW⁺/Freiburg. The importance of the additional resonance f_Z relies on two aspects:

- 1) knowing the distance d and the plasma frequency f_N , f_Z allows in principle to deduce the electron temperature T_e .

⁺ IPW = Institut für Physikalische Weltraumforschung.

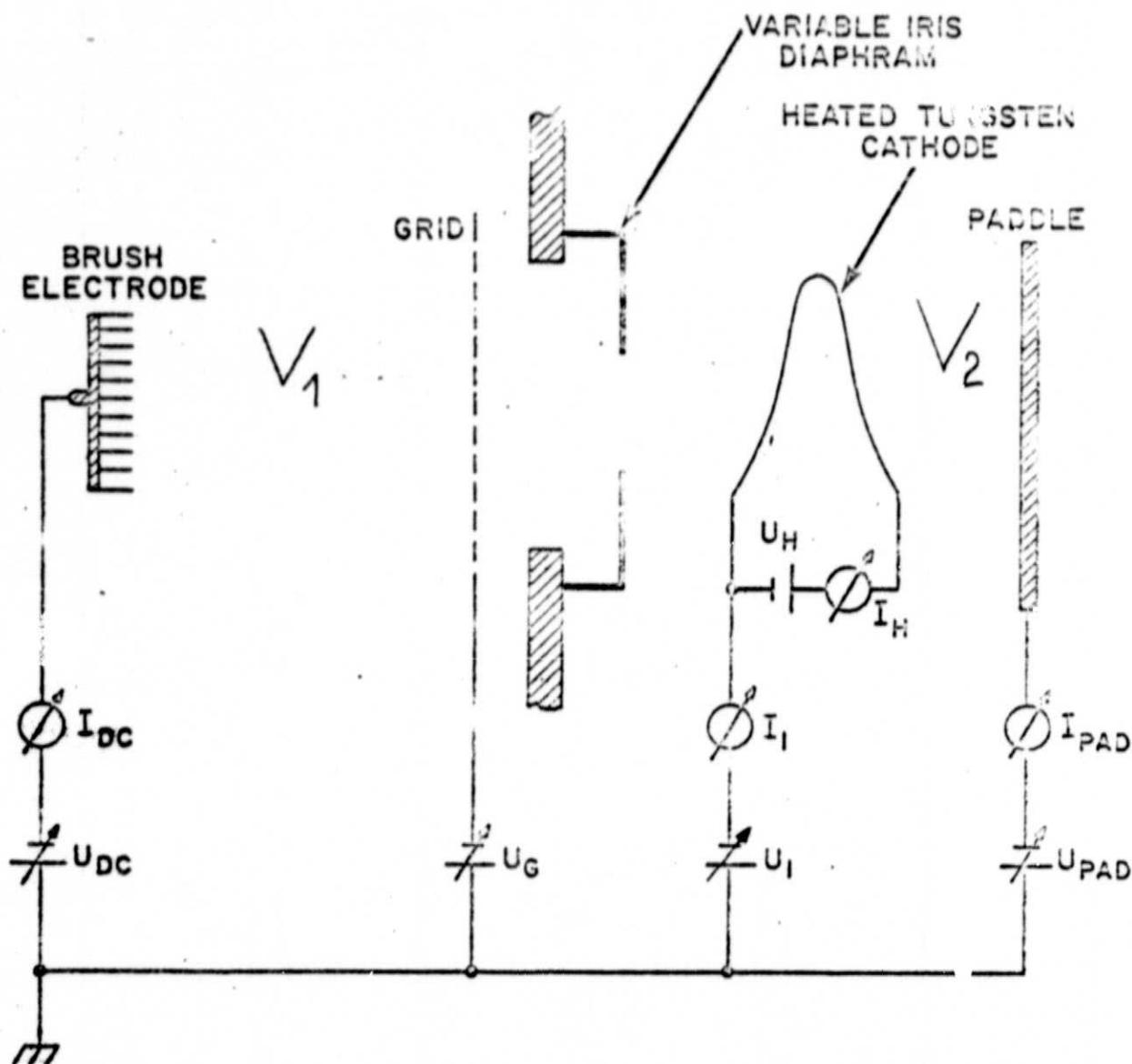
- 2) This method would allow to determine T_e with high temporal resolution (10^{-1} to about 10^{-2} sec) which would be of particular value for diagnostic measurements in space plasmas as well as non stationary laboratory plasmas.

Acknowledgement:

The author wishes to thank Prof. W. Heikkila and Dr. D. Winningham for valuable discussions and B. Milam for his engineering assistance.

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PLASMA SOURCE

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FIG 1

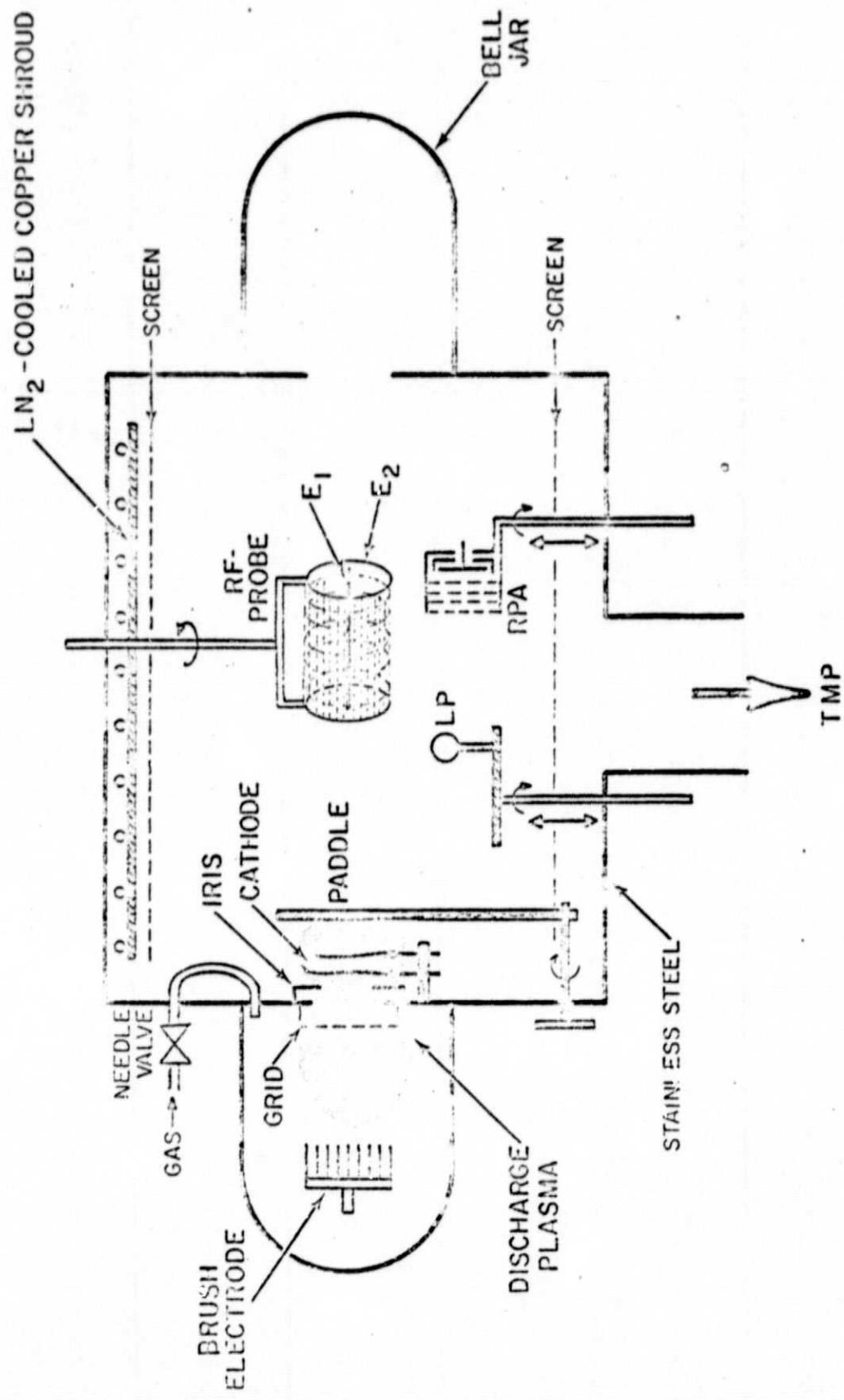
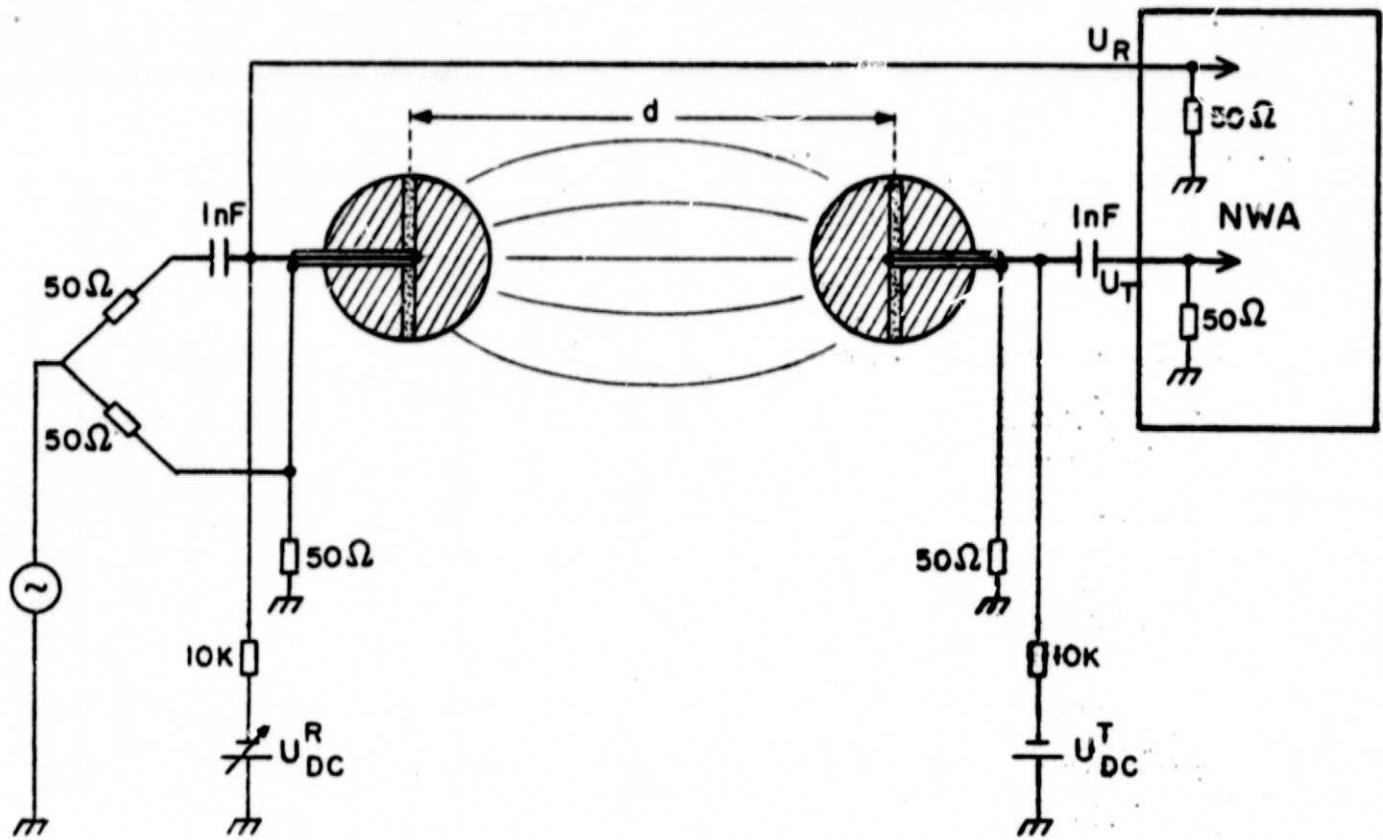
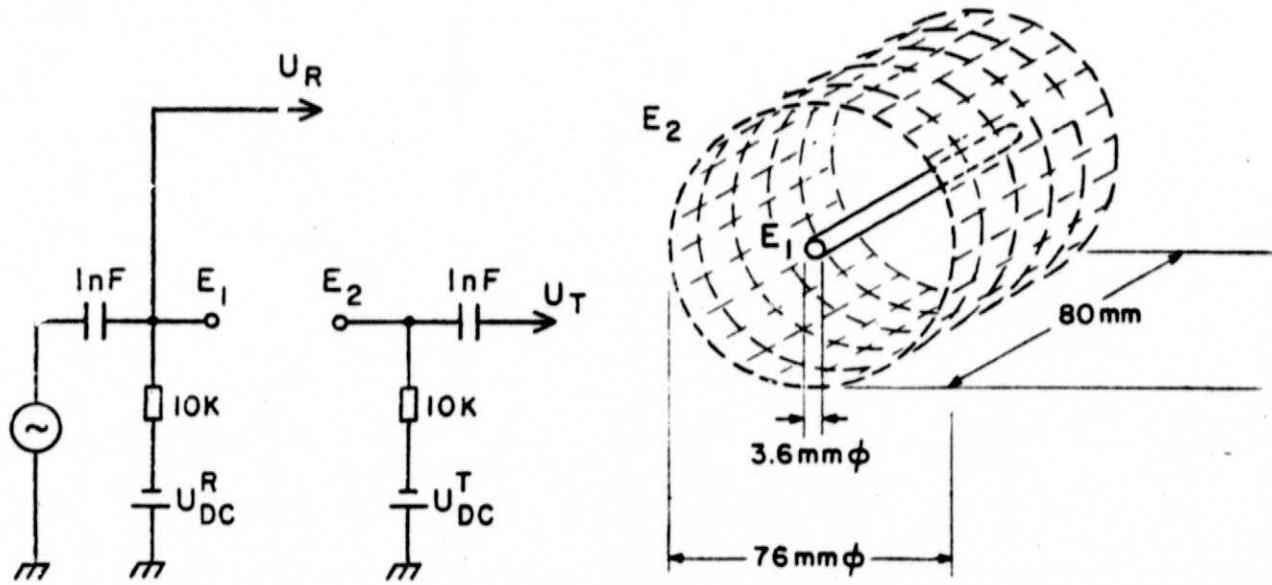


FIG 2



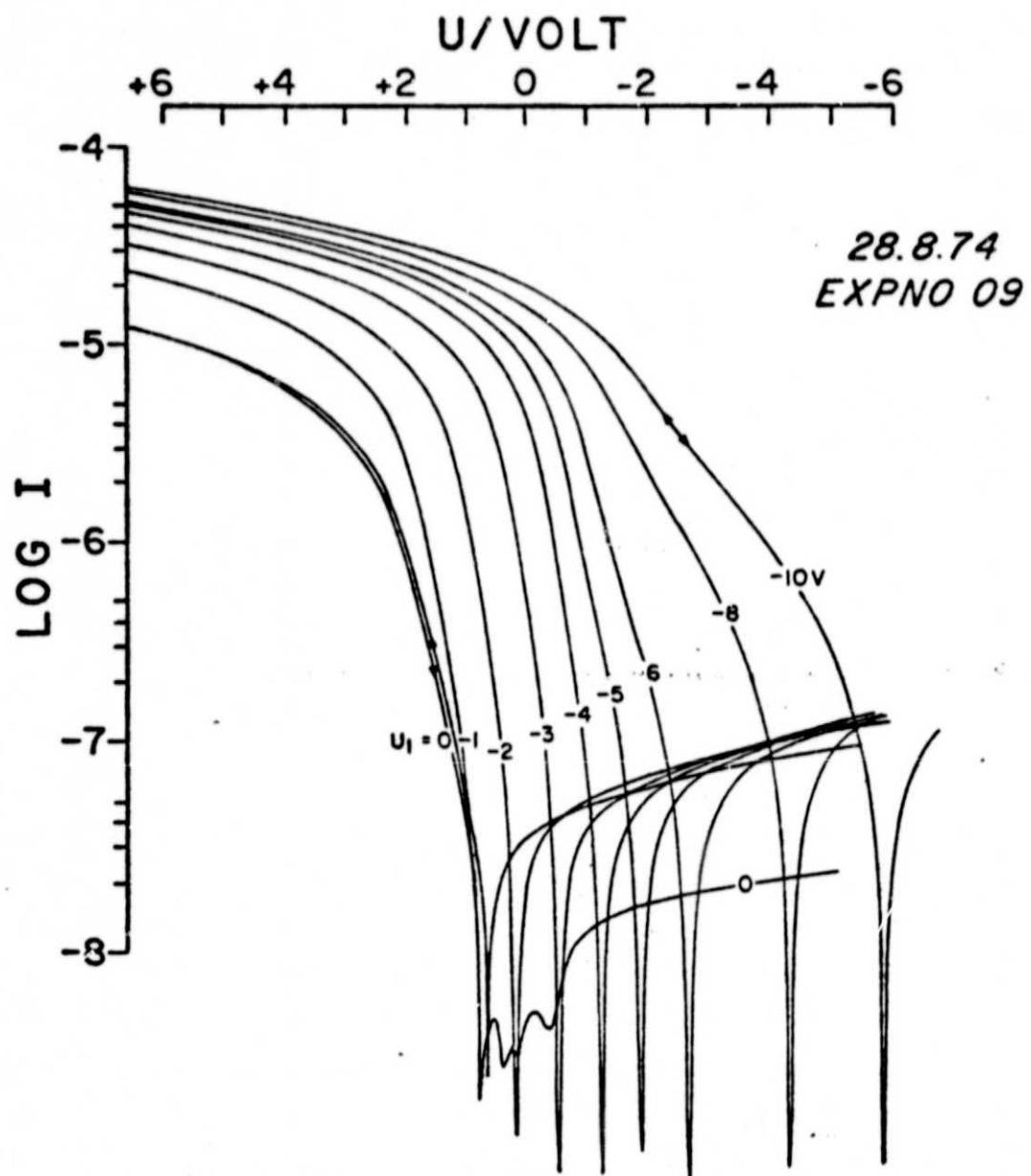
SPHERICAL RF - PROBE

DIAMETER OF BOTH SPHERES: 17.8 mm



CYLINDRICAL RF - PROBE

FIG 3



SPHERICAL LANGMUIR PROBE
STAINLESS STEEL
DIAMETER 10mm
VARIATION OF U_1

FIG 4

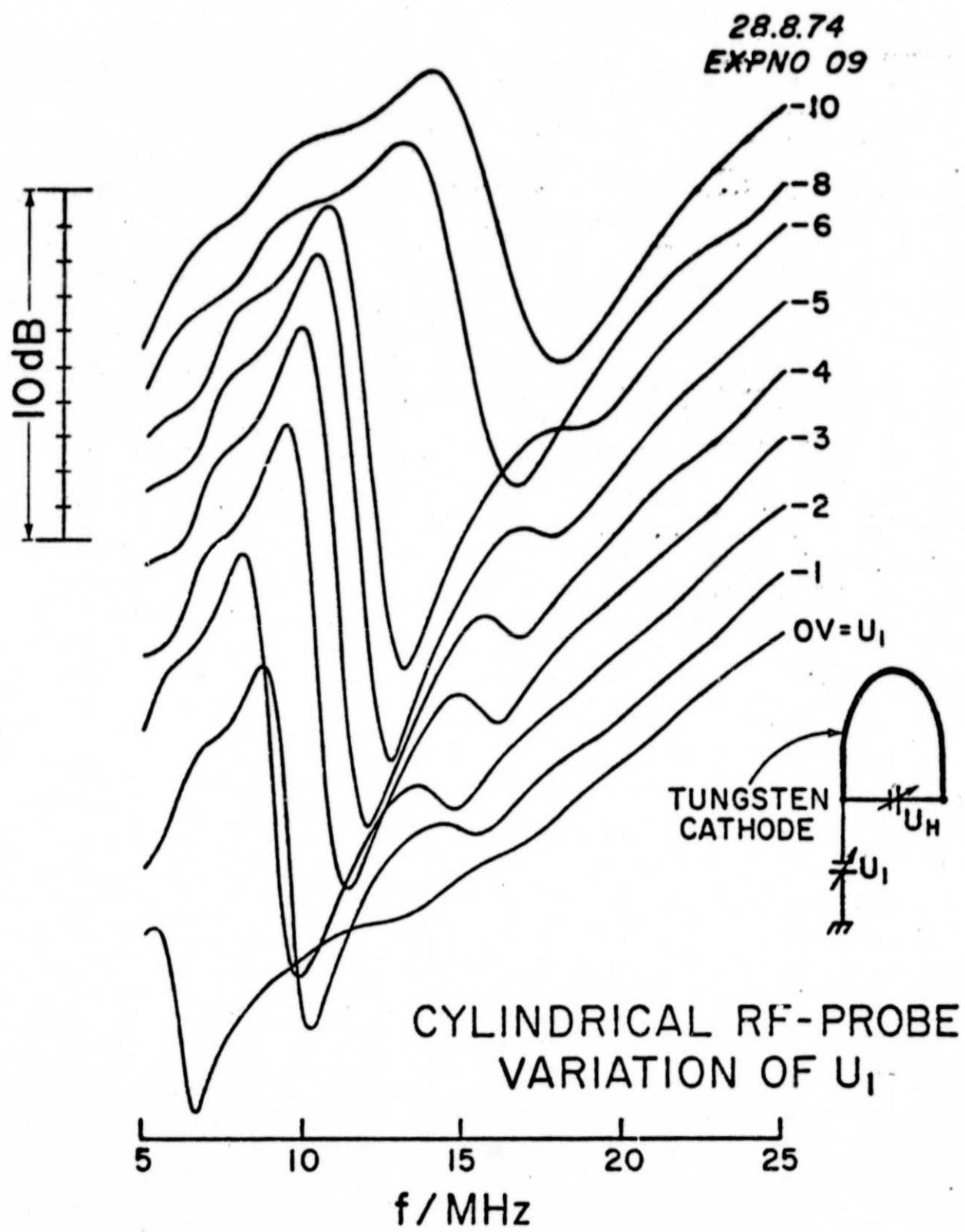


FIG 5

28.8.74
EXPNO 05

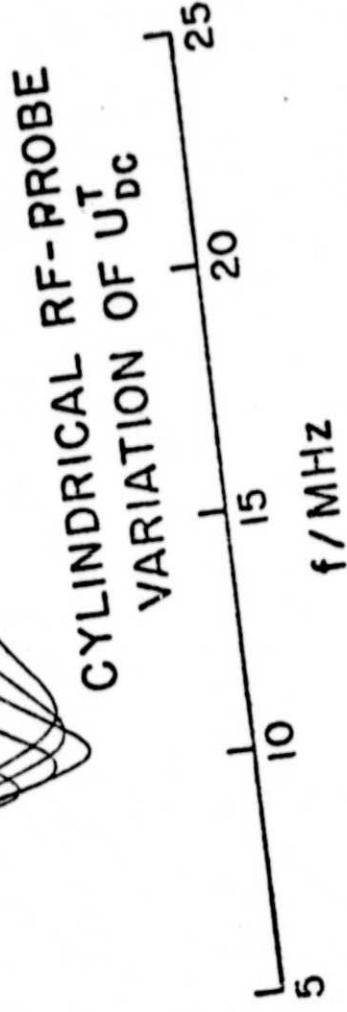
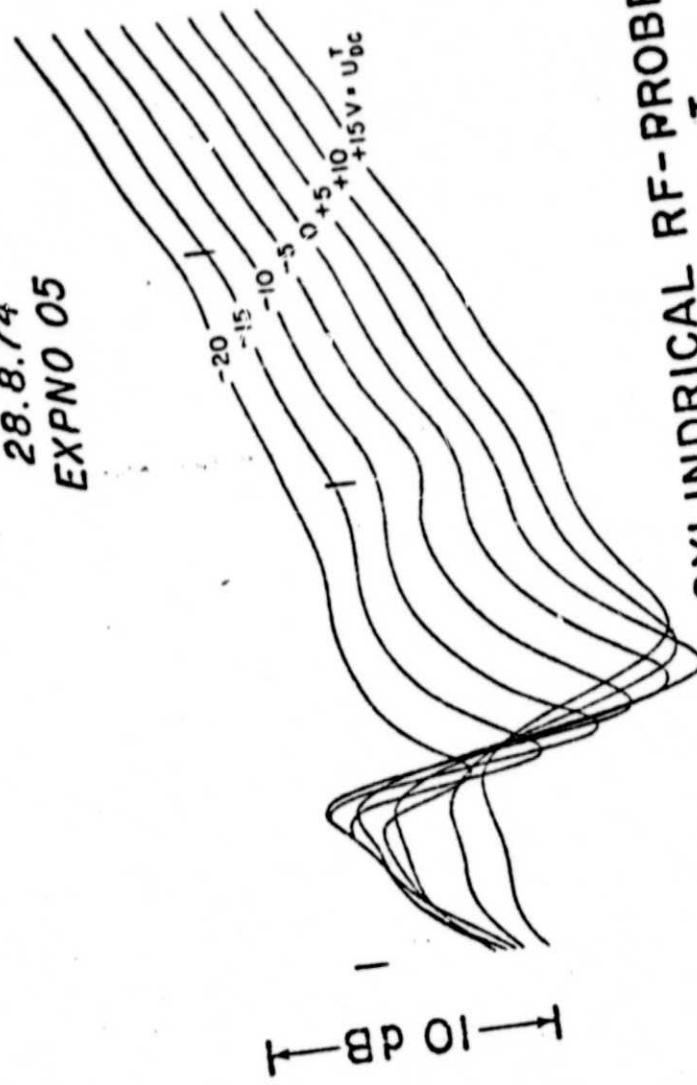


FIG 6

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NO.	1	2	3	4	5	6	7
d/mm	92.8	83.8	74.8	65.8	56.6	47.6	38.8

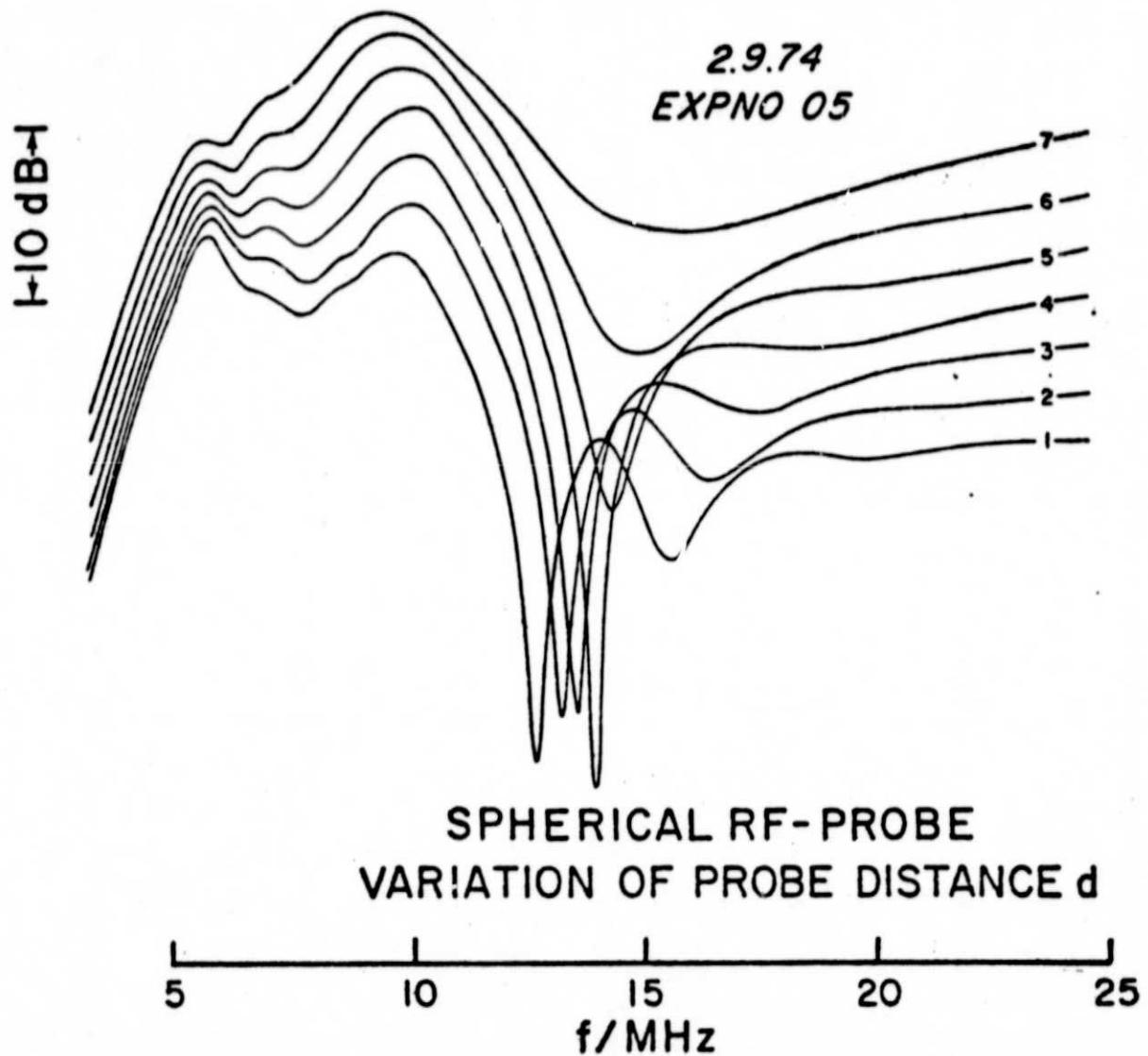
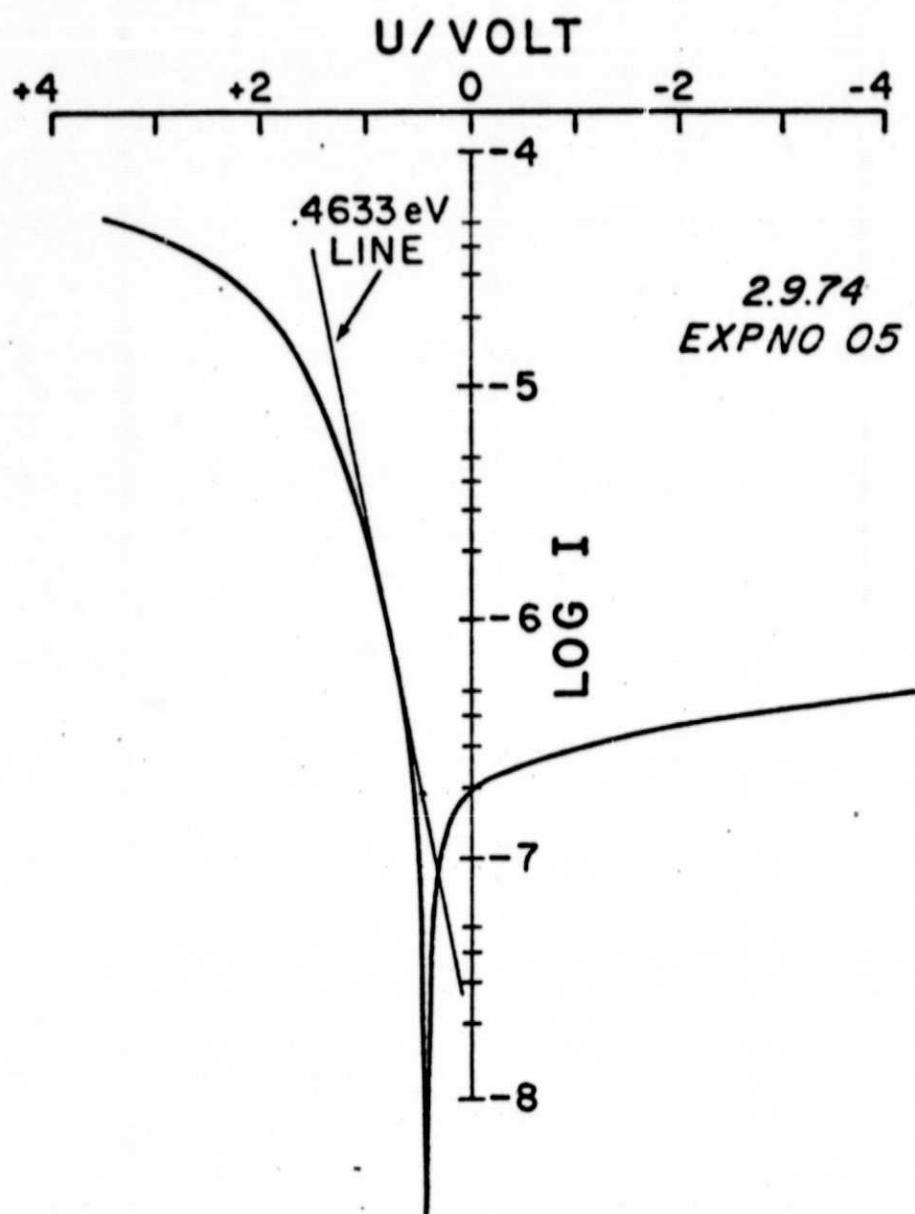


FIG 7



SPHERICAL LANGMUIR PROBE
STAINLESS STELL
DIAMETER :0mm

FIG 8

OPERATION OF A DIGITAL LANGMUIR PROBE
ON LINE WITH A PDP 11/45 DIGITAL COMPUTER

by

RAINER KIST*

This memo describes the concept and the performance of the Digital Langmuir Probe (DLP) experiment, the necessary interface electronics to the computer and the associated software. The system was set up to provide a flexible diagnostic tool for the laboratory plasma facility at the University of Texas at Dallas (UTD). The memo summarises a part of the accomplishments achieved in the course of a project which deals with production and diagnostics of collisionless laboratory plasmas at UTD.

UTD, September 1974

*On leave at UTD, sponsored by the European Space Research Organization (ESRO), now European Space Agency (ESA).

I. INTRODUCTION

Several diagnostic probes such as RF-probe, Retarding Potential Analyzer (RPA) and Langmuir Probes (LP) have been installed in the Laboratory plasma chamber at UTD. Langmuir Probes of different materials (Stainless Steel, Polymorphic carbon) and geometry (spherical, cylindrical) have been used. Fig. 1 shows the arrangement of the probes within the chamber. The detailed description and performance of the plasma source and the probes are the object of a separate memo.

A conventional Langmuir probe electronics makes use of an electrometer amplifier with either a nonlinear (diode) feedback resistor or a linear feedback resistor plus subsequent logarithmic amplifier. This allows to display the logarithm of the probe current over 3 to 4 orders of magnitude (current-voltage characteristic). This compressed form of current display, however, does not allow for a sufficient resolution of small current changes as they occur in time and/or space due to density fluctuations associated with electrostatic waves on instabilities present in a plasma.

In order to measure small electron density fluctuations in the F-region of the Equatorial Ionosphere a digital Langmuir Probe (DLP) was developed at UTD by D. Winningham and J. B. Smith for use in the EQUION rocket project. The unique feature of this experiment is to provide an absolute current resolution of $\sim 10^{-9}$ Amps and a maximum relative resolution of $\sim 10^{-4}$.

Since the investigation of electrostatic wave modes and instabilities is of special interest for laboratory plasma physics, this DLP was installed for use in the plasma chamber at UTD. In particular the digital output of the instrument allowed for a straight forward connection

to the computer (PDP 11/45). Therefore an interface electronics and a set of computer programs were set up to transfer the data to the computer and from there on to magnetic tape and process them for display on a Calcomp plotter.

A general diagram of the system DLP-Computer is shown in Fig. 2. The main parts of the system are described below in more detail.

II. Properties of the DLP - Electronics*

A triangular bias waveform is applied at G (see Fig. 3) through the electrometer amplifier (1) to the Probe P. The laboratory version of the DLP allows for using the waveform of either the internal or an external bias generator. The range for the bias voltage is from -1 to +3 volts. The period τ of the internal bias generator is controlled by the bit rate fed into the experiment and can be varied between $.5 \text{ S} \leq \tau \leq 200 \text{ S}$. The relationship between τ and the bit rate f_b is

$$\tau/\text{S} = \frac{23040}{f_b/\text{Hz}}$$

The electrometer amplifier is a 3420L BURR-BROWN with bias current of about 1 pA and frequency response better than 2 kHz.

The bias waveform at G also appears at A, B, and C. Therefore the bias is also introduced at J so that Amplifier 2 can see the bias as a common mode signal, and can reject it, making D independent of the bias and responsive only to the signal produced by the input current at A. One of the important system tests consists of holding the input current

*This chapter is essentially the DLP electronics description that already had been prepared by D. Winningham and J. B. Smith for the EQUION-Project.

constant and letting the bias voltage cycle while observing the output code. If the system is properly adjusted, the output code will not change by more than 1 or 2 LSB's.

The principle of operation is obvious; only a few system constants will be specified here. The A/D converter is a 0 to -10 v full scale, 8 bit unit. Of the total range of 256 increments (called minor increments) only 200 are used, leaving an unused portion at the lower and upper edges of the 10 volt range. The limits of the 200 increment range are determined by voltage comparators. Actually the comparators defined a range of 200 increments plus a hysteresis band of a few increments in order to avoid an oscillatory condition when sitting at band edge. This means that certain values of current can be represented by two different code group differing by 200 minor increments and by 1 major increment. However, when the two code groups are decoded according to a fixed algorithm, exactly the same current results.

When a voltage comparator switches it changes the D/A converter code by one increment (called a major increment). The resulting output analog increment is fed into the system at J which resets the output D by 200 minor voltage increments.

The D/A is an 8 bit unit in which the 256 increments correspond to an output voltage from -10v to +10v. This range establishes the maximum measuring limits of the system, and R_1 is chosen so that the desired maximum current will cause a $\pm 10v$ change at B. However the bias voltage must be added to this which results in a range of -11 v to +13 v at B. With a ± 15 volt supply, the +13 v limit exceeds the linear range of operation of amplifiers 1 and 2. Therefore R_1 is chosen to be $786 \text{ K}\Omega$

which results in a maximum voltage at B of $7.86 \text{ v} + 3\text{V} = 10.86 \text{ v}$ for an input current (electrons) of $10\mu\text{a}$. This means that the positive range of the D/A will not all be used. In the negative direction (positive ion current) the maximum current will be even smaller, and is not expected to exceed 15% of the negative range capability.

The sense of the output code is arranged as follows: At the negative limit (-10v of positive ion current at B, all code bits are zero. As the current changes so as to move B in a positive direction, the code increases and at +10V all bits are 1.

At zero current (0 V at B) the code is

DAC		ADC	
MSB	LSB	MSB	LSB
0 1 1 1	1 1 1 0	1 1 0 0	1 0 0 0

Here the ADC code is 200. It cannot be 0 for zero current because the upper level comparator excludes this point from the operating region. Therefore a major increment is "subtracted" (the DAC LSB = 0) and the ADC increased from 0 to 200.

The code/current algorithm is:

$$i = [(DAC - 127) 200 + ADC] (5 \times 10^{-10}) \text{ where}$$

DAC = the decimal value of the D/a code

ADC = the decimal value of the A/d code

i = amperes (positive i means electrons flowing to the system. A negative i means positive ions flowing to the system).

5×10^{-10} = the resolution or amps/minor increment

When applied to the above code the result is:

$$i = [(126 - 127) 200 + 200] (5 \times 10^{-10}) = 0$$

If the current increases by a few minor increments, say 15, the lower level comparator will trip and the resulting code will be:

0 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1

Applying the algorithm

$$i = 15 (5 \times 10^{-10}) = 75 \times 10^{-10} \text{ a.}$$

The algorithm applies to all values of current.

In reading the value of the analog channel only 1 fact is necessary: The gain of Amplifier 3 is exactly -0.5. If D is -6 v, F is +3v, etc. If the ADC code is known the voltage at D and F can be computed. The ADC increment is 10v/256 = 39.0625 m.v. (40 mv is close enough). Therefore

$$V_D = - (\text{ADC}) .04 \text{ volts}$$

$$V_F = (\text{ADC}) .02 \text{ volts}$$

$$\text{or ADC} = 50 V_F$$

from which the algorithm can be applied,

$$i = [(D - 127) 200 + 50 V_F] (5 \times 10^{-10}) \text{ amps}$$

III. The Interface Electronics

The Interface Electronics (IE) provides matching of the experiment output signal to the driver assembly and allows for operation of the DLP in different modes. In more detail the following functions are realized; we partly follow the schematic diagram. Fig. 4 and the timing chart Fig. 5.

- 1) The bit rate is to be provided by an external pulse generator.

The word and frame rates are deduced from the bit rate.

- 2) The serial output signal DAC-ADC of the DLP is stored in a

16 bit storage register from where it will later be transferred

in parallel to the computer via 4 each quadruple 2-line to 1-line multiplexers.

- 3) The voltage of the internal or external bias generator is offset by +1.33V and then fed to an A/D-Converter. The A/D-Conversion is ordered by a strobe pulse generated in the programmer.
- 4) The converter is also used for A/D-Conversion of the probe position monitoring voltage (position sweep). This applies for the operation mode of the experiment, in which the probe is kept at constant bias voltage and moved within the plasma.
- 5) A set of eight toggle switches allows for monitoring the experiment number (EXPNO) or a coded STATUS in order to identify a particular data run (measurement).
- 6) Upon a select signal from the programmer the DAC/ADC data or the BIAS (or position)/EXPNO (or STATUS) data is alternately switched by the multiplexers to the driver assembly and then via optical couplers to the receiver section of the computer. Sixteen bits are transferred in parallel to the computer receiver but are not actually read into the computer until a cycle request pulse is generated by the programmer. The rate at which the data points are sampled is 366 per scan. It is independent from the scantime, since both, scantime and sampling period are fixed multiples of the bit period.
- 7) The programmer generated cycle request pulse commands the computer to read the data at its receiver inputs and to then follow the instructions given by the computer program for data storage and/or reduction.

IV. The Computer Software

At present the software for the L.P-Computer system consists of three programs

- 1) Storage and Tape Transfer Program (PROBE), ASSEMBLER
- 2) Tape dumping Program (DLP), FORTRAN IV
- 3) Data Analysis Program (DIGITAL LANGMUIR PROBE), FORTRAN IV

PROBE handles the data flux that is coming from the DLP-experiment through the interface electronics IE to the receiver input of the computer. 16 bit data words are stored in the upper core memory and arranged in blocks of 8K Bytes. The part of memory used allows for storage of 22 blocks which form one file. One data block covers the data of 5.5 Scans of the Digital Langmuir Probe. As already mentioned the number of data samples taken per scan is 366 independently of the scantime. Thus with each run (measurement) practically 5 Langmuir Characteristics (each consisting of a full sweep upwards and a full sweep downwards) can be recorded. Prior to each measurement a computer attention button on the IE has to be pushed. This starts the computer to read 8 K bytes of data into the memory. A switch installed at the IE allows to interrupt the data flux.

Once up to 22 data blocks are stored they are transferred on to tape by executing PROBE with one label card for each block. The label card contains additional information (80 bytes) about the particular measurement such as file Number, block number, date and experimental conditions (pressure, probe used, etc). The data sequence on tape is thus: label card information - data block label card information - data block- A.S.O. After each 22nd block an End of File (EOF) mark is written on the

tape. When executing PROBE for data transfer on to tape a 00 card inserted right after the label cards takes care of reinitializing the memory so that a new set of 22 measurements can be stored upon pushing the computer intention button.

For short compilation of the procedure in handling the program PROBE see the copy of the printer record in Appendix A.

The Program DLP reads the tape for a selected set of files and blocks and prints the data in 32 columns of octal numbers. The sequence of the data display is

EXPNO - ADC - DAC - BIAS

The selection of file Number (NF) and block (or record) number (NR) is made via a data card which contains the number of records to be read (MAXREX) in column 5, the number of records to be skipped (NRS) in column 10 and the number of files to be skipped (NFS) in column 15.

Fig. 6 shows the flow diagram for this program; a copy of the printer record of DLP is included in appendix B.

The program DIGITAL LANGMUIR PROBE in its present version meets the following objectives:

- 1) Skip a specified number of files and records and print label (or header) card.
- 2) Identify bias and find first bias peak. The bias identification relies on the fixed sequence of DAC/ADC/BIAS/EXPNO and the fact that the experiment number (toggle switch setting at the IE) is constant throughout one run.
- 3) Calculate current i out of DAC/ADC according to the algorithm given in Chapter II.

4) Calculate the derivative $T_G = 11606.9 \frac{\Delta U}{\Delta \log i}$

5) Print EXPNO, Bias, $\log i$ and T_G

6) Plot data for one cycle (scan) on CALCOMP - Plotter

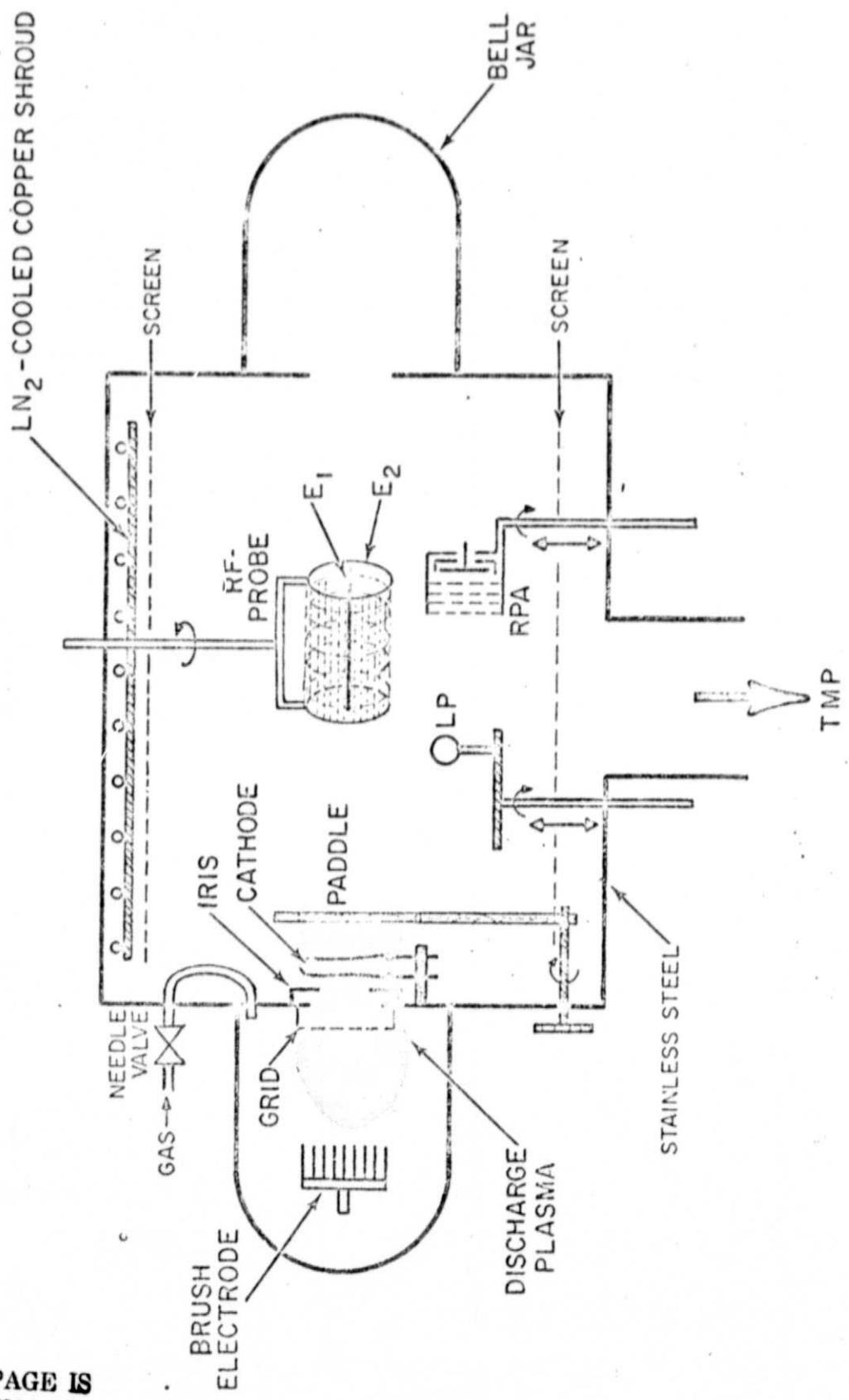
A simplified flow chart of this program is shown as Fig. 7, a copy of the program is included as appendix C.

Figs. 8 and 9 show two examples of Langmuir characteristics as semilogarithmic plots produced by the system. The current for increasing bias voltage is marked by x-es, for decreasing bias by squares. The ion current is plotted as log of its absolute value. The probe used in the plasma was a stainless steel sphere of 5 mm diameter. The surface was discharge cleaned for 10 minutes in nitrogen at about 10μ pressure. The Langmuir curves show almost no hysteresis. In Fig. 8 the floating potential is at +100 mV. In this experiment the plasma was clearly non-Maxwellian since the differential or "generalized temperature" T_G shows a monotonous increase. Here crosses are for the upward going and triangles for the downward going part of the curve. Fig. 9 shows a case where the distribution function of the electrons is close to Maxwellian. This shows up in the shoulder shaped part of the T_G - curve, occurring between 1 and 1.4 Volts and corresponding to an electron temperature T_e of about 5000 K. For an ideally Maxwellian distribution the shoulder would have a horizontal plateau. A high value of T_e corresponds to a large, a low T_e -value to a small horizontal extension of the plateau. The low T_G -values on the left side reflect the drop of the measured total current due to the ion current which becomes significant with decreasing bias voltage. The high T_G -values on the right side are due to the transition-knee from the retarding to the saturation regime of the

characteristics. This knee is influenced by the inhomogeneity of the work function over the probe surface. A perfectly homogeneous work function would produce a sharper knee of the electron current curve and a correspondingly straightened shape of the T_G -plateau.

Above 2.5 V bias the data are meaningless since in this case the current exceeded the upper current limit (10^{-5} amperes) to which the electronics of the Digital Langmuir Probe was set.

ACKNOWLEDGEMENT: The author is highly indebted to Dr. D. Winningham for providing the DLP back up electronics of the EQUION-project. Many thanks go to N. Eaker and C. Thompson for designing and building the interface electronics. The outstanding help from Dr. J. Midgley, L. Wedel and D. Beck in providing parts of the necessary software is particularly appreciated. The author finally wishes to express his gratitude to E. Milam for his engineering assistance.



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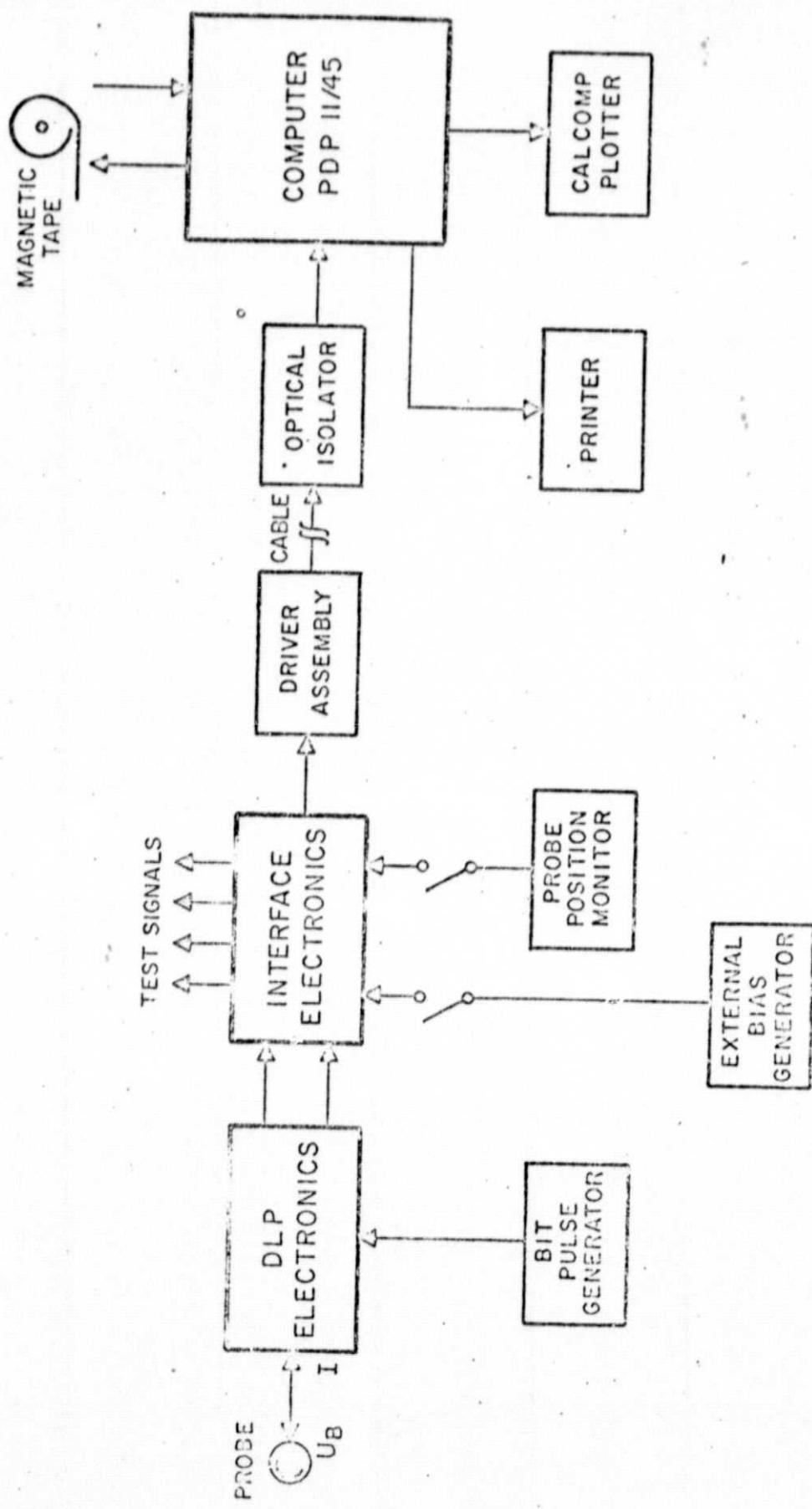


FIG. 2. SYSTEM DLP-COMPUTER

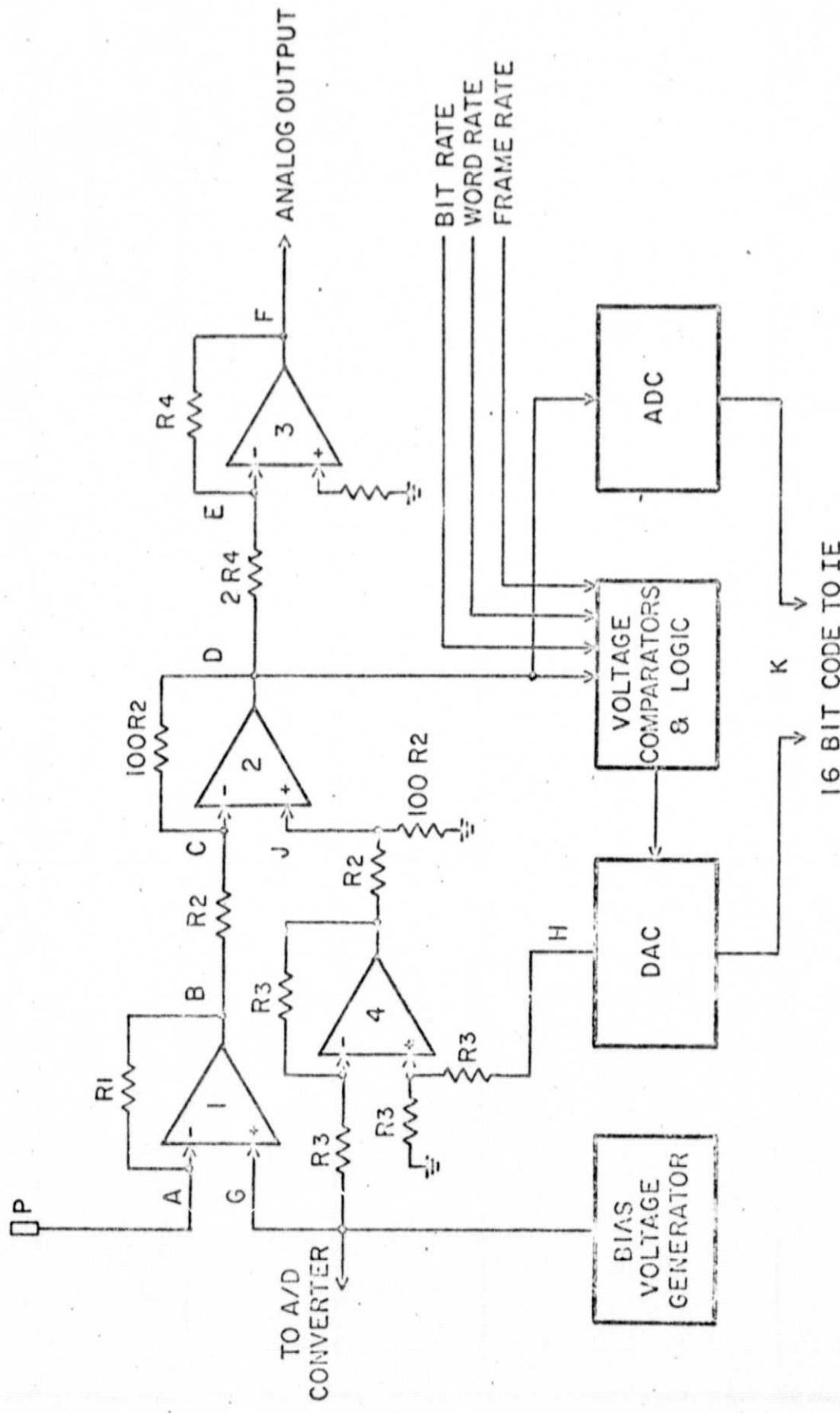
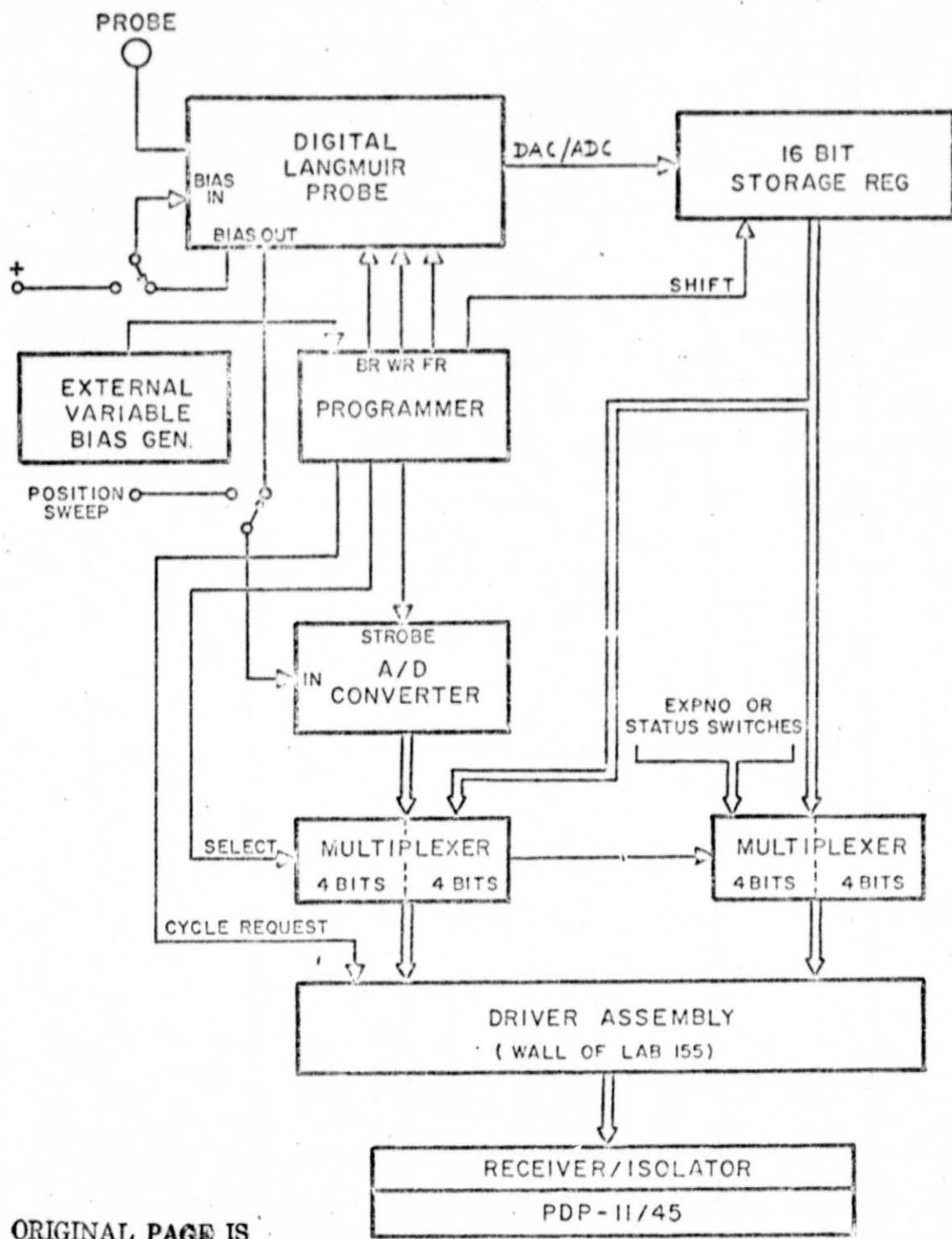
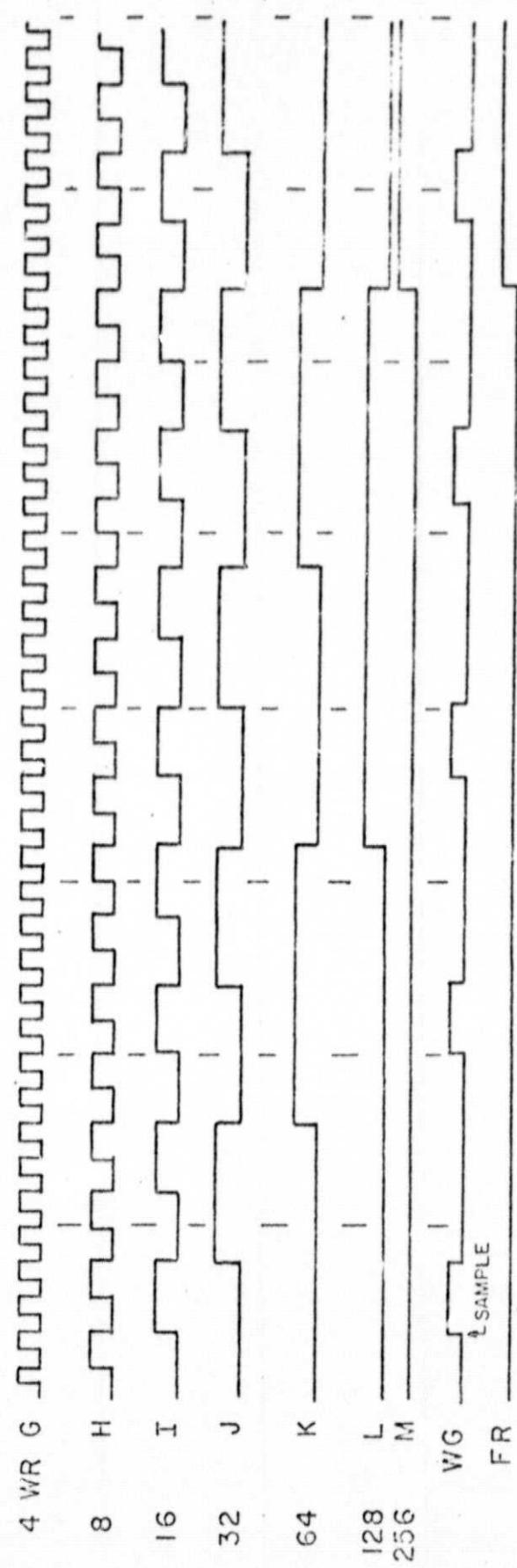
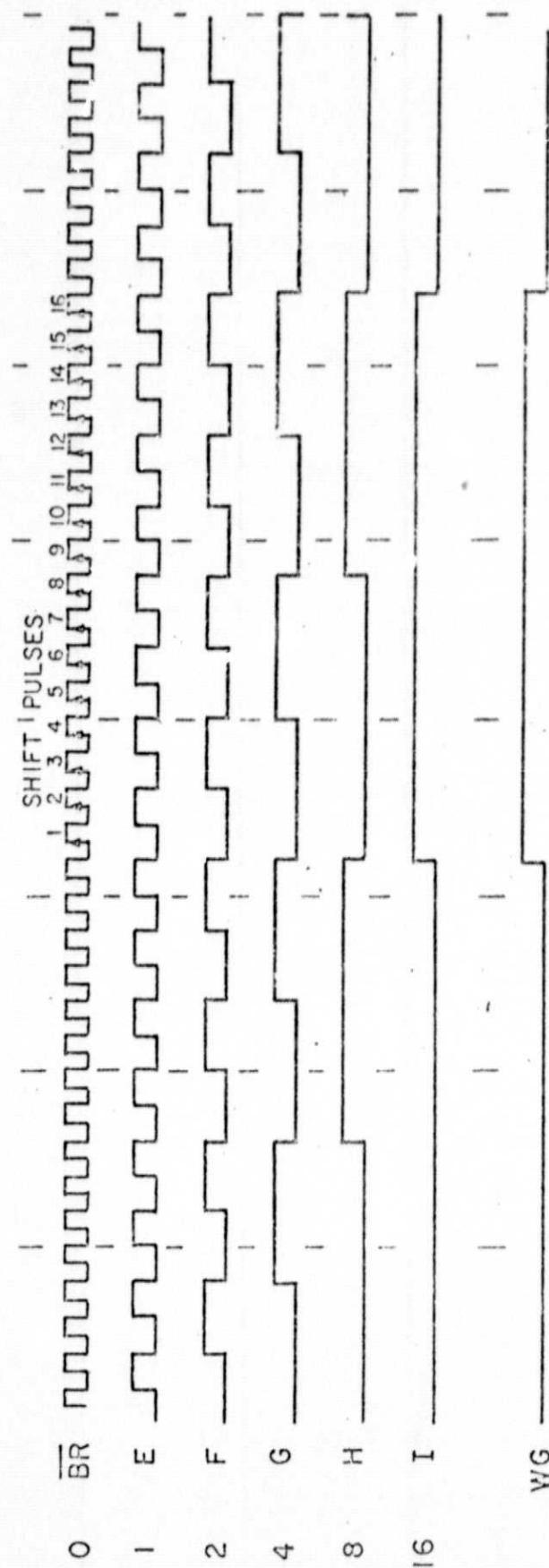


Fig. 3 DIGITAL LANGMUIR PROBE



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FIG. 4



A/D STROBE
CYCLE REQ
(CR)

SEQUENCE OF DATA:

DAC/ADC - BIAS/EXPNO ONE SAMPLE

$$WG = I\bar{J} \quad STROBE = IJ$$

$$FB = \bar{I}M$$

DLP tape dumping program

Fortran III

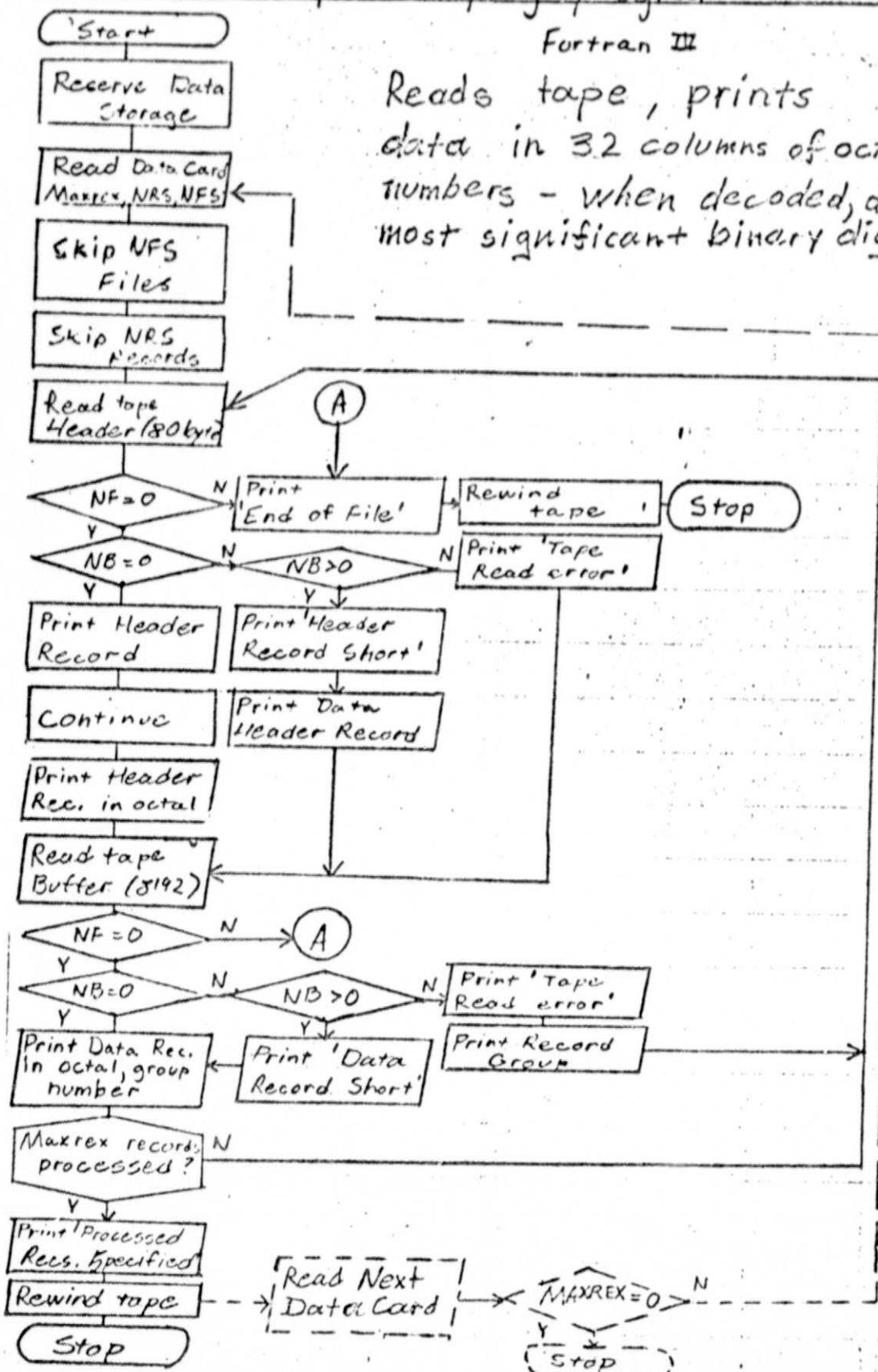
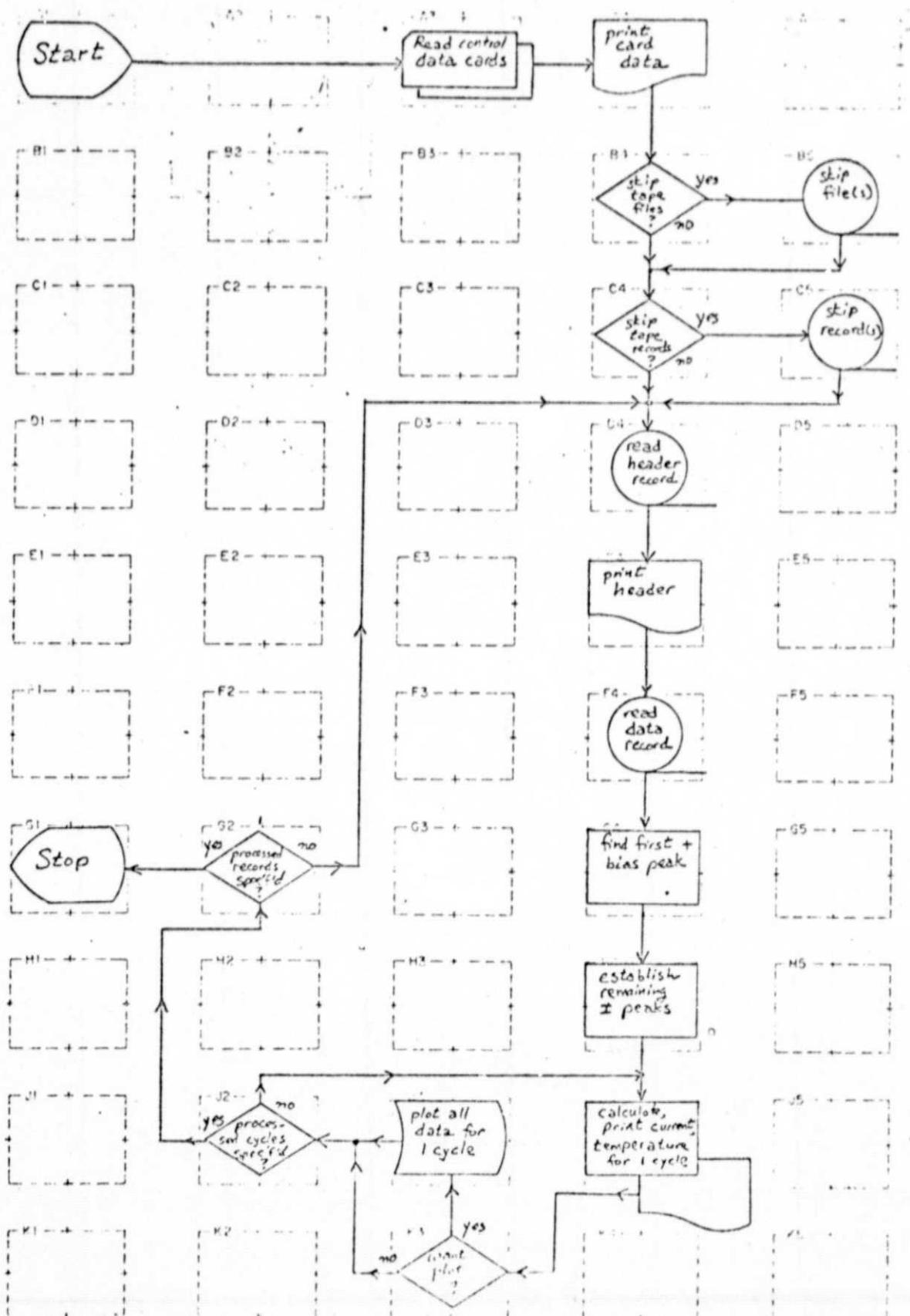


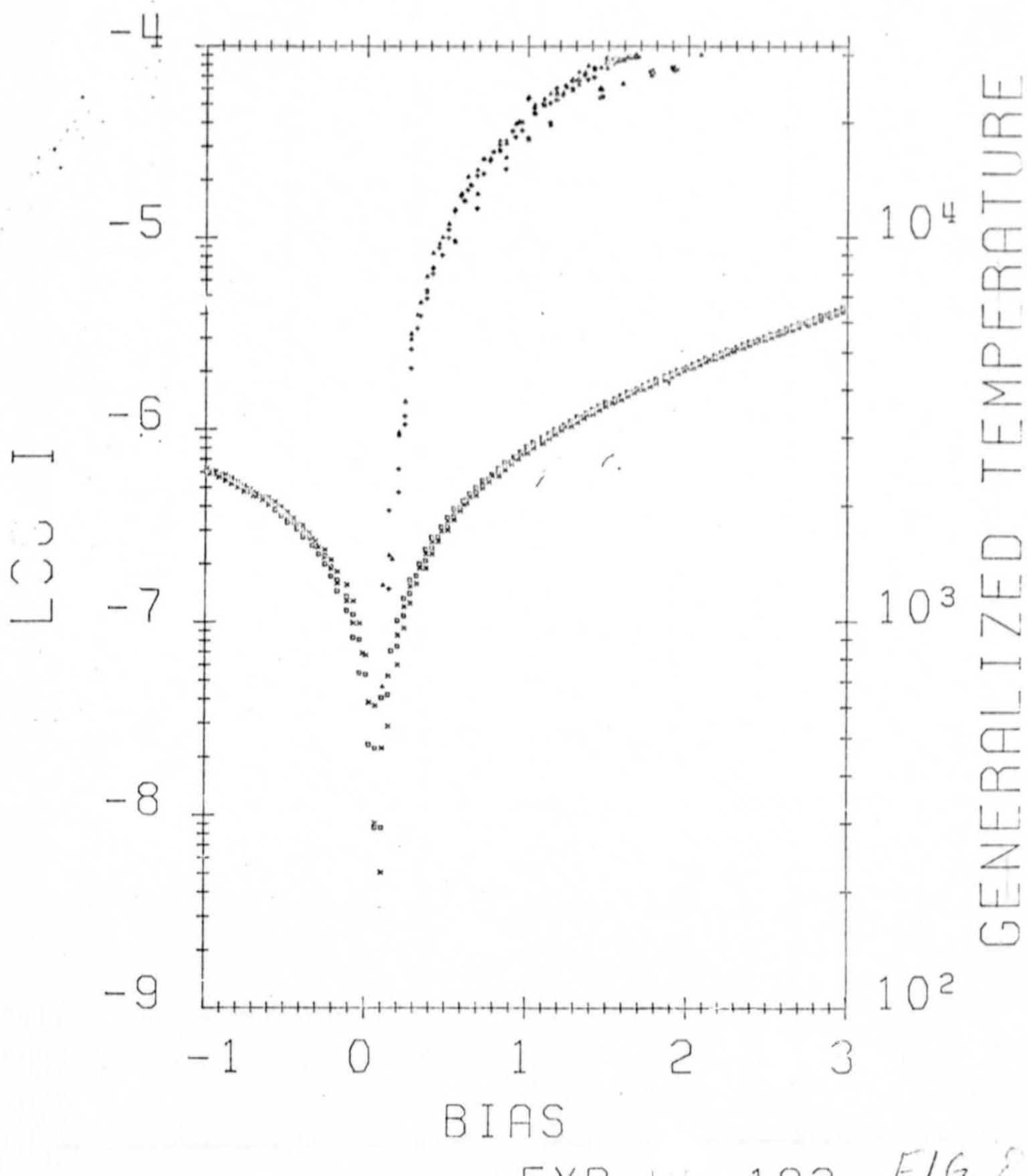
FIG. 6

IBM Flowcharting Worksheet

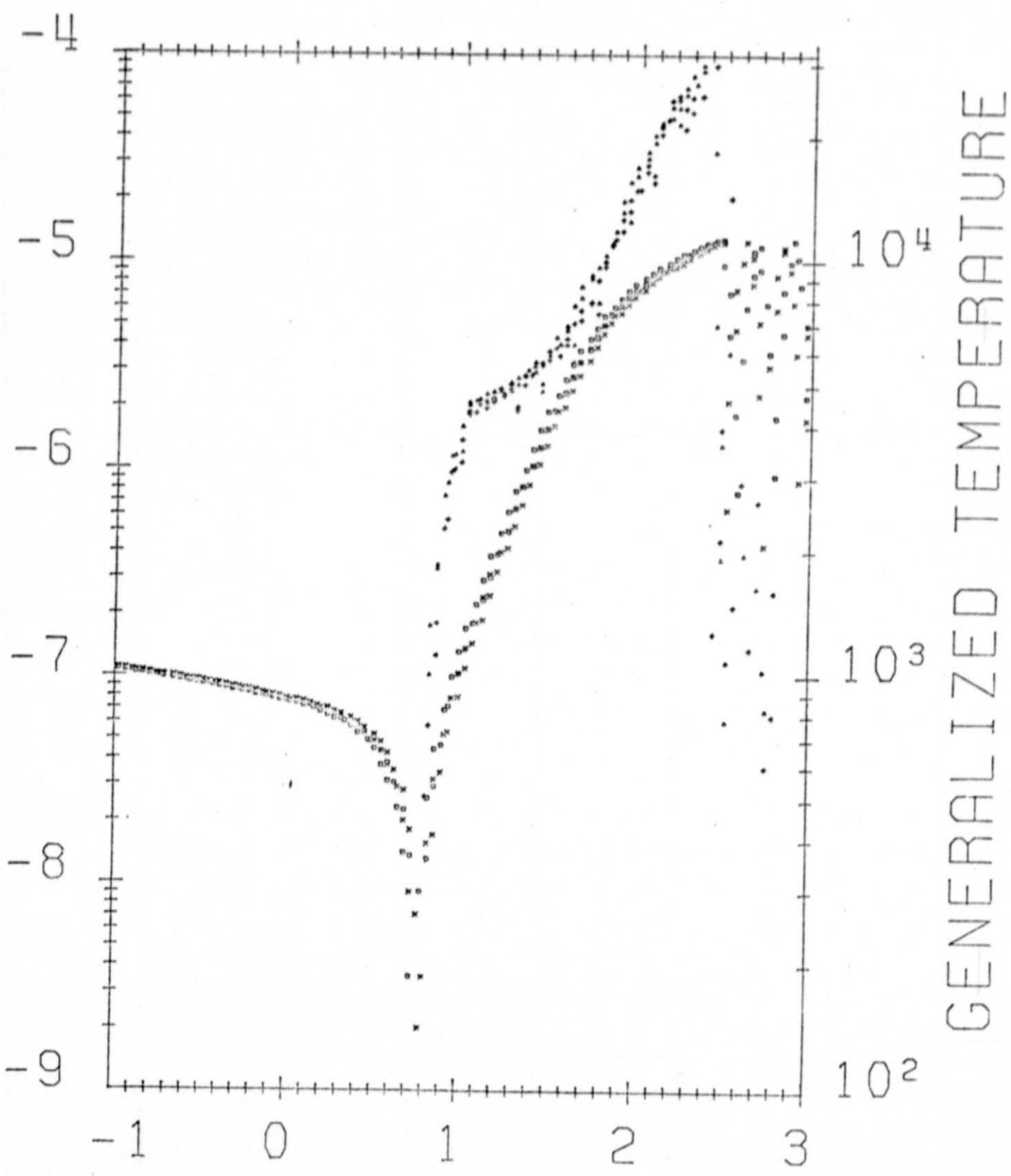
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Programmer: L.B. Wadel Program No.: Date: 9/25/74 Page: A
Chart ID: Chart Name: Program Name: LFANGMR





LOG I



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09/26/74 EXP NO 63 FIG. 9

APPENDIX A

```

2 *LIST ITW
3 *TITLE PROBE
4 * PROBE OPERATES SIMULTANEOUSLY WITH NORMAL BATCH PROCESSING.
5 * IT ACCEPTS 16 BIT DATA WORDS, IN BLOCKS OF 4K WORDS, STORING THEM
6 * IN UPPER MEMORY, AND (WHEN INSTRUCTED) DUMPING THEM ON TAPE AS A FILE.
7 * A MAXIMUM OF 22 SUCH BLOCKS MAY BE STORED BETWEEN DUMPS.
8 * WHEN PROBE IS RUN, ONE DATA (LABEL) CARD MUST BE INCLUDED FOR EACH
9 * BLOCK TO BE WRITTEN. THE CONTENTS OF THE CARD ARE WRITTEN AS AN 82
10 * BYTE LABEL RECORD PRECEDED BY THE 8K BYTE DATA RECORD. THE FIRST TWO
11 * DIGITS ON THE FIRST CARD SPECIFY THE FILE NUMBER INTO WHICH THE FIRST TWO
12 * BLOCKS ARE WRITTEN. A NO CARD (CARD WHOSE FIRST TWO COLUMNS ARE ZERO)
13 * FOLLOWING THE LAST LABEL CARD CLOSES THE FILE AND REINITIALIZES
14 * MEMORY TO STORE ANOTHER 22 BLOCKS.
15
16 * PROCEDURE: 1) EXECUTE PROBE WITH ONLY A NO CARD, TO INITIALIZE MEMORY
17 * 2) PUSH ATTENTION BUTTON TO START A DATA BLOCK
18 * 3) START DATA AND STOP IT AFTER 4K WORDS OR MORE.
19 * 4) REPEAT 2) AND 3), PUT NO MORE THAN 22 TIMES.
20 * 5) EXECUTE PROBE WITH ONE LABEL CARD FOR EACH BLOCK TO BE
21 * RECORDED ON TAPE, AND A NO CARD TO REINITIALIZE MEMORY.
22 * 6) REPEAT 2)-5) AS OFTEN AS DESIRED, INCREASING FILE
23 * NUMBER ON LABEL CARDS BY ONE EACH TIME.
24
25 *GLOBAL-TAPE
26 *CALL *INIT, *READ, *WAIT, *RLSE, *EXIT
27 *INIT=104           * THE ADDRESS WHERE INT IS STORED
28
29 *PROBE: *INIT *LNKCR
30 *READ *LNKCR, *CARD * READ ONE DATA CARD
31 *WAIT *LNKCR
32 *MOV IN, $1
33 *NOV IN, $1
34 *B4C $177760, $1
35 *PIC $177760, $0
36 *MUL $12, $1
37 *ADD $1, $0
38 *B8
39 *222124
40 *125
41 *222222
42 *222076
43 *220032
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997 *220226
998 *220222
999 *220226
1000 *220222
1001 *220226
1002 *220222

```

```

58 000156 002674 WORD IN
59 002160 001721 WORD NB
60 002162 001051 *WORD NR
61 002164 016702 002626 *WORD NR
62 000170 002767 000002 000620 451 GET BUFFER ADDRESS
63 000176 010031 ADD *2, ADR
64 002220 042703 177717 NOV *0, $1
65 000224 050067 002464C BIC #177717, $0
66 000210 052067 002472G BIS #0, TAPE+464
67 002221 042701 177760 RJS #0, TAPE+472
68 002220 000321 BIC #177760, $1
69 002222 072127 000004 ASH #4, $1
70 002226 010167 000222 NOV #1, 95
71 000232 012767 002200 000562 NOV #2000, NB
72 000240 024567 0000022G JSR #5, TAPE
73 000244 000415 BR $5
74 000246 001036 WORD TWO
75 000250 001020 *WORD IC
76 000252 000022 *WORD
77 000254 001021 *WORD NB
78 000256 001021 *WORD NR
79 000260 024567 0000000G *WORD TWO
80 000264 000412 PR 75 JSR #5, TAPE
81 000266 021035 *WORD TWO
82 000270 001021 *WORD IC
83 000272 002674 *WORD IN
84 000274 001032 *WORD ZERO
85 000276 021026 *WORD NR
86 000300 005757 000522 *WORD TWO
87 000324 003242 TST HR
88 000346 004567 0000000G PGT 15
89 000312 000422 BR BS JSR #5, TAPE
90 000314 001040 *WORD OFFLIN
91 000316 001021 *WORD IC
92 000322 0000000G *WORD
93 000326 012737 000174 RESET! NOV #174
94 000334 012737 000176 NOV #176
95 000342 012731 000516! NOV #176
96 000346 012722 000104 NOV #176
97 000352 012732 000010 NOV #176, $0
98 000356 012122 951 *MOVE THE INTERRUPT HANDLER INTO RAM
99 000360 0000000G *MOVE
100 000362 0000000G *MOVE
101 000366 012737 005237 172340 CLR #172340, $0
102 000374 012737 004346 000176 NOV #172342, $0
103 000402 012737 000516! NOV #172354, $0
104 000410 012733 000104 NOV #172356, $0
105 000414 012737 000010 NOV #172356, $0
106 000420 012733 0000000G NOV #172356, $0
107 000424 010337 010337 172342 NOV #172356, $0
108 000430 010337 010337 172342 NOV #172356, $0
109 000434 012701 140000 NOV #172356, $0
110 000442 012702 0000000G NOV #172356, $0
111 000444 012700 010200 NOV #172356, $0
112 000450 012767 000216 000340 NOV #172356, $0
113 000456 000237 SPL 7
114 000460 012737 000001 177572 NOV #177572, $0

```

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115 220466 212122 1061 MOV (%1)+,(%2)+ 1 MOVE PROGRAM TP UPPER CORE
116 2202470 077022 SOB $2,10$ 1
117 2202472 075037 177572 CLR $177572 1 CLEAR MEM MGMT
118 220476 202233 SPL 2
119 2212730 012737 - 001600 - 172354 NOV $1600,0*172354 1 K46=1600
120 2202526 012737 000100 172434 NOV $100,0*172434 1 NNARL INTERRUPT
121 22027514 122 RETURN TO BATCH STREAM-TO-WAIT FOR ATTN.

122 123 000516 012737 - 022001 177572 --- INT: 124 0220524 002137 022536! *USABL LSB
124 0220524 002137 022536! NOV $1,0*177572 1 NNABLE MEM MGMT
125 0222537 025037 177572 JMP %$177572 1
126 0220534 000002 RTI
127 0220536 032737 020002 172434 - STORE: BIT $200000,0*172434 1 IS ATTN BIT SET?
128 0220544 001025 BNE 25
129 0220546 012737 000102 172434 - NOV $100,0*172434 1 IF NOT, NNABLE INTERRUPT
130 0222554 002137 000116 151 JMP %$49INT+12 1 AND RETURN TO WAIT
131 0220562 032737 023002 -172434 - 25: BIT $200000,0*172434 1 KEEP TESTING ATTENTION BIT
132 0220566 021374 BNE 25
133 0222570 026712 000222 -000072 - CMP ADR,$72 1 HAS LAST RUN ALREADY BEEN MADE?
134 0220576 002365 BGE 15 1 HAS LAST RUN ALREADY BEEN MADE?
135 0220582 026262 000202 -000210 - ADD -$2,ADR 1 IF SO, RETURN TO BATCH STREAM.
136 0220586 016720 000204 NOV ADR,%0
137 002512 010001 NOV $0,%1
138 0220614 042701 177760 BIC $177760,%1
139 0220620 000321 SWAB $1
140 141 0220622 072127 000204 ASH $4,%1
142 0220622 012737 172432 NOV $1,0*172432 1 SET STARTING ADDRESS
143 0220632 012737 172002 172430 NOV $-10200,0*172430 1 AND WORD COUNT
144 0220640 042700 177717 BIC -$177717,%0 1 GET HEN EXIT BITS
145 0220646 062702 000101 ADD $101,%0 1 COMBINE WITH CONTROL
146 0220652 012037 172434 NOV $0,0*172434 1 START ACCEPTING DATA
147 0220656 020002 -LNKCR1- BR 15
148 0220650 114700 WORD 2
149 0220652 000001 RAD50 /XXX/
150 0220664 026753 WORD 1
151 0220666 027122 - 000000 - CARD1 RAD50 /BI/
152 0220674 0200023 TINI! WORD 0
153 021016 0200023 BLKH 82.
154 021020 0200022 ADMIN WORD 20
155 021022 0001023 IC: WORD 0
156 021024 0200023 NB: WORD 120
157 021026 0004054 NF: WORD 0
158 021023 077777 NR: WORD 54
159 021032 000002 ZERO WORD 77777
160 021034 177777 ONE WORD 1
161 001036 177776 TWO WORD -2
162 021040 0200024 OFFLIN: WORD 4
163 000001 END PROBE

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PROBE MACPO VR05A 19-SEP-74 10:11:19 PAGE 1+

SYMBOL TABLE

ADR	021216R	CARD	000666R	IC	001020R
IN	022674R	INT	000516R	LANKCR	000656R
MINT	000124	NB	001022R	NF	001024R
NR	021026R	NRV	001030R	OFFLIN	001040R
ONE	001234R	PROBE	000002R	RESET	000326R
SP	*000206	STORE	000536R	TAPE	***** G
T.C.	021036R	ZERO	001032R	.SYM	0000027
ABS.	022722				
	003				
	00142				
	001				

ERRORS DETECTED 0
FREE CORE: 12529, WORDS

ERRORS DETECTED 0
FREE CORE: 12529, WORDS
- PROBE, LPI<PROBE

1
2
3
4
5
6
7

8 SRU LINK
LINK_VIA_C1
SPROBE,LP1<PROBE,FTNLIST[1,1],L/E

- LOAD MAP PROBE .LDA ----- 10:19:59 - 19-SEP-74
- TRANSFER ADDRESS: 154724
- LOW LIMIT: 154724
- HIGH LIMIT: 157462

- MODULE PROBE
- SECTION ADDRESS SIZE
< . ABS. > 000000 002000
< > 154724 001042

- MODULE TAPE
- SECTION ADDRESS SIZE
< > 155766 001472
- TAPE - 155766

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LINK VITAL

8 GUN PROBE

STI T14F1-10120124

APPENDIX B

```

DLP DIRECTIONS!
C USE DATA CARD TO SPECIFY RECORD READING
C PUT MAX RECS. COL. 5, NO. RECS. SKIP COL. 10, FILES SKIP COL. 15
C REPEAT CARDS, USE 0 FOR MAXREX IN LAST CARD.
C
C 0221   BYTE BUFFER (8192), HEADER(80)
C          EQUIVALENCE (BUFFER(1), HEADER(1))
C          CONTINUE
C          N = 0
C
C          C          SKIP MODULE
C          READ (8 1001) MAXREX, NRS, NFS
C          1001 FORMAT (3I5)
C          IF (MAXREX .EQ. 0) GO TO 7200
C          2 IF (NFS .LE. 0) GOTO 5
C          NB = 0
C          NR = 50
C          NF = 1
C          CALL TAPE(-1,0,BUFFER,NB,NR,NF)
C          NFS = NFS - 1
C          GO TO 2
C          5 CONTINUE
C          6 IF (NRS .LE. 0) GO TO 10
C          NB = 0
C          NR = 2
C          NF = 1
C          CALL TAPE(-1,0,BUFFER,NB,NR,NF)
C          NRS = NRS - 1
C          GO TO 6
C          12 CONTINUE
C          13 NR = 80
C          NP = 1
C          NF = 1
C          IF (N .GT. MAXREX) GO TO 55
C          3 CALL TAPE (-1, 0, HEADER, NB, NR, NF)
C          2229 IF (NFS .EQ. 0) GO TO 20
C          20 IF (NB) 21, 28, 23
C          21 WRITE (5, 541)
C          2232 541 FORMAT(1IEND OF FILE!)
C          2233 GO TO 22
C          2234 21 WRITE (5, 542) N
C          2235 542 FORMAT(1IITAPE READ-ERROR ON HEADER, RECORD-GROUP', 17)
C          2236 GOTOC200
C          2237 23 WRITE (5, 543) NB, N, HEADER
C          2238 543 FORMAT(1IHEADER RECORD SHORT BY!, 13, 1, RECORD-GROUP', 17 /
C          1, 101, 80A1)
C          2240 28 WRITE (5, 555) HEADER, N
C          2241 555 FORMAT(1B1, 80A1, 20X, 1HEADER RECORD GROUP', 17)
C          C          TEMPORARY! PRINTS OUT OCTAL FORM FOR DIAGNOSES OF TAPE.
C          C          WRITE (5, 955) HEADER
C
C 0222   4
C 0223
C 0224
C 0225
C 0226
C 0227
C 0228
C 0229
C 0230
C 0231
C 0232
C 0233
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C 0336
C 0337
C 0338
C 0339
C 0340
C 0341
C 0342

```

2243 955 FORMAT ('0', 3204)

C 202 CONTINUE

2245 NB = 8192
2246 NR = 1
2247 NF = 1
2248 CALL TAPE ('-1', 2, BUFFER, NB, NR, NF)
2249 IF (NF .EQ. 0) GO TO 20
2250 IF (NB) 221, 228, 2232251 221 WRITE (5,5221) N
2252 5221 FORMAT('ITAPE READ-ERROR ON DATA, RECORD=GROUP', I7)

2253 GO TO 1

2254 223 WRITE (5, 5223) NB
2255 5223 FORMAT('ITDATA RECORD SHORT BY', I7)2256 228 CONTINUE
2257 WRITE (5,5228) N

2258 5228 FORMAT('ITDATA, RECORD=GROUP', I7 //)

2259 WRITE(5,5229)(BUFFER(I),I=1,8000)

2260 5229 FORMAT(' ', 3204)

2261 N = N+1
2262 GO TO 12263 55 CONTINUE
2264 WRITE (5,5555)MAXREX

2265 5555 FORMAT('PROCESSED NUMBER OF RECORDS=GROUPS SPECIFIED',I5)

2266 22 CONTINUE
2267 CALL TAPE (4, 0)

2268 GO TO 4

2269 7000 CONTINUE
2270 STOP
2271 END

END

ROUTINES CALLED:
TAPEBLOCK LENGTH
MAIN. 4880 (023040)*

COMPILER ---- CORE

PHASE USED FREE
DECLARATIVES 00456 13234
EXECUTABLES 02627 12883
ASSEMBLY 01471 14936

SRU LINK
LINK V11A01
#DLP<#DLP,FTNLIB[1,1]/L/E
TRANSFER ADDRESS: 117764
LOW LIMIT: 117764
HIGH LIMIT: 157460
LINK V11A01

SRU DLP
#EOC

DIGITAL LANGUAGE PROBE

```

C DATA CARDS #1
C
C   NOMINAL MAX PEAK VTR (E
C   MIN (E/F FORMAT) COLS 1-12
C   TOLERANCE (E/F ) 13-24
C   DATA POINTS BETWEEN POS. PEAKS (I FORMAT) 25-36
C   DATA POINTS PUS TO NEG (I ) 37-41
C
C   DATA CARDS #2
C
C   NUMBER OF FILES TO SKIP (I FORMAT) 1-5
C   NUMBER OF RECORDS TO SKIP AF-
C   TEK ANY FILE SKIPPING (COUNT
C   BOTH HEADING RECORDS AND DATA
C   RECORDS) (I ) 6-10
C   NUMBER OF RECORDS TO PROCESS
C   (COUNT ONLY DATA RECORDS) (I ) 11-15
C   NUMBER OF CYCLES TO PROCESS
C   (LEAVE BLANK IF WANT ALL)
C   IN EACH RECORD (I ) 16-20
C   1 IF PLOT WANTED. ELSE 0 OR BLANK
C   25
C
C   REAL*4 CUHLOG (500) * BYAS (500) * TE (500) * F (500)
C   INTEGER*2 IDATE(13) * IBUF(4096)
C   INTEGER*2 PEAK (2)
C   INTEGER*2 INTRH, INTRB
C   INTEGER*2 MAXMIN(40)
C   REAL HUFFEL(1912) * BUF(1912) * INTERB(2) * HDH(72)
C   REAL PBUF(14000)
C
C   EQUIVALENCE (HUFFEL(1) * BUF(1)) * (INTRH, INTERB(1)), *
C   * (IDATE(1) * HUFFEL(1))
C   EQUIVALENCE (BUF(1), IBUF(1))
C
C   DATA NAV / 3 /
C   DATA ISW / 0 /
C   DATA BSCALE / 1.95312E-2 /
C   DATA INTRH / 0/ KHEC / 0/
C   DATA TSCALE / 1.16069E4 /
C   DATA PEAK / * * * * /
C   DATA OFFSET / 1.33 /
C
C   READ (8,8008) PMAX, PMIN, TOL, LMAX, LMIN
C   8008 FORMAT (2E12.0, 2I5)
C   * (I5,5T0) PMAX, PMIN, TOL, LMAX, LMIN
C   5700 FORMAT (10I8 MAX=*,FH,3,*,MIN,*,FB,3,*,OTOLERANCE =*,F8.3/
C   * ASSUMED MAX-TU-MAX= 15, *, MAX-TO-MIN=, 15)
C   READ (8,8005) NF, MAXHEX, KX, IPLT
C   8005 FORMAT (5I5)
C   * F (KX * LE, 0) KX = 19
C   * F (KX * GT, 19) KX = 19
C   * F (IPLT * Nt, 0)
C   1 CALL CALCMF (PAUF, 9000, 53, 0)
C   * WRITE (5,5707) NF
C   5707 FORMAT (10I8 FILES SKIPPED=*, 14)
C   * IF (NF * LE, 0) GO TO 2
C   * NR = 0
C   * 32000
C   CALL TAPE (-1*0, BUFFER, NR, MR, NF)
C   WRITE (5,5701) NF

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IF (INF • NF • 0) STOP
2 CONTINUE
  WRITE (5,5701) MAXREK, NH, KX, IPLT
  5701 FORMAT (10MAX, RECODOS • 15• 5X, 'RECORDS SKIPPED', 15• 5X,
1• MAX CYCLES PROCESSED PER RECORD', 15• 5X, 'PLUT CODE', 13)
  KX = 2 • KX - 1

C   IF (NH • LE• 0) GO TO 5
    NR = 0
    NF = 1
    CALL TAPE (-1• 0, BUFSIZE, NB• NR• NF)
    WRITE (5,5702) NH
    5702 FORMAT (10AFTER SKIPPING, NR DECREMENTED TO, 13)
    S CONTINUE
    IF (KREC • EQU MAXHEX) GO TO 888
    C   HEAD MDR RECORD. WAIT FOR COMPLETION
      KREC = KREC + 1
      NR = 80
      NP = 1
      NF = 1
      CALL TAPE (-1• 0, BUFSIZE, NB• NR• NP)
      C   IF (NF • NE. 1) GO TO 999
        READ ERHUF OH SHORT RECORD?
      C   IF (NH) 10, 20, 30
        C   GOOD RECORD
        20 CONTINUE
        WRITE (5,5005) MDR, KREC
        5005 FORMAT ('1• 72A1• 20X, 'RECORD NO.' IS //')
        C   SAVE DATE FROM MEAVER RECORD TO PLOT
        DO 25 I = 1, 3
        25 IDATE (I) = IIRUF (I• 1)
        C   HEAD DATA RECORD • WT FOR COMP.
        300 CONTINUE
        NR = 8192
        NP = 1
        NF = 1
        CALL TAPE (-1• 0, BUFSIZE, NB• NR• NF)
        EOF?
        C   IF (NF • NE. 1) GOTO 999
        READ ERHUF OH SHORT RECORD?
        C   IF (NH) 310• 320• 330
        C   GOOD RECUHU
        320 CONTINUE
        C   FIND PHASE
        J = 3
        DO 40 I = 6• 10, 4
        IIRUF (I2) •NE. BUF (I) ) GO TO 50
        40 CONTINUE
        DO • 51 = • 02, • 18, •
        IIRUF (I2) •NE. BUF (I) ) GO TO 50
        5 CONTINUE
        GO TO 60
        50 CONTINUE
        J = 5
        DO 55 I = 6• 20, 6
        IIRUF (I2) •NE. BUF (I) ) GO TO 70
        55 CONTINUE
        DO 75 I = • 04, • 20, •
        IIRUF (I2) •NE. BUF (I) ) GO TO 70
        75 CONTINUE
        GO TO 60
        70 CONTINUE

```

C 60 CONTINUE

INTERH(1) = HUF(IJ-1)

EXPNR(1) = INTEH

WRITE(5, 5015) EXPNR(1)

5015 FORMAT('EXPERIMENT-NUMBER', 05, ' OCTAL')

FIND POSITIVE BIAS PEAK

DO 80 I = J, 811, 7*

INTERB(I) = HUF(I+3)

IF (INTEH .NE. EXPNR(I))

INTEH(I) = HUF(I+2)

BIAS(I) = INTEH

BYE = BSCALE*BIAS(I)

IF (BYE .GE. (PHAK-TOL)) GO TO 100

80 CONTINUE

120 CONTINUE

WRITE(5, 5020)

5020 FORMAT('PEAK NOT FOUND')

GO TO 5

100 CONTINUE

INTERB(I) = HUF(I+6)

IF (INTEH .LT. BIAS(I)) GO TO 110

BIAS(I) = INTEH

I = I + *

GO TO 100

110 CONTINUE

MAXMIN(I) = I + 2

DO 210 I = 2, 40

210 MAXMIN(I) = 0

DO 220 I = 2, 38, 2

MAXMIN(I) = MAXMIN(I-1) + 4 * LMIN

ITEMP = MAXMIN(I-1) + 4 * LMAX

IF (ITEMP .GE. MIN) (U TO 230

INTERH(I) = HUF(ITEMP+1)

IF (INTEH .EQ. EXPNR(I)) GO TO 240

INTERH(I) = HUF(ITEMP + 1)

IF (INTEH .NE. EXPNR(I)) GO TO 230

240 MAXMIN(I+1) = ITEM

220 CONTINUE

230 CONTINUE

TABULATE BIAS, DAC, ADC, F STARTING AT FIRST POSITIVE PEAK

C DAC IS IN HUF(I+5)

C BIAS HUF(I+6)

C DO 200 K = 1, KX, 2

KU = MAXMIN (K+2)

IF (KU .EQ. 0) GO TO 5

KH = MAXMIN (K+1)

KL = MAXMIN (K)

LCTR = 99

N = 0

DO 400 KK = KL, KU, *

N = N + 1

IF (KK .EQ. KM) NMID = N

INTERH(I) = HUF (KK-2)

ADC = INTEH

INTERH(I) = HUF (KK-1)

DAC = INTEH

F(N) = (IDAC - 127) * 200 * ADC * 5.E-10

FABS = ABS(F(N))

IF (FABS .EQ. 0.) FAHS = 1.E-35

CUHLOG(N) = ALOG10(FAHS)

INTERH(I) = HUF (KK)

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BYAS (N) = HSCALE * BIAS(N) - OFFSET
INIT TE SO CAN DETECT LATER IF ACTUALLY CALCULATED

TE (N) = 1.E-35

400 CONTINUE

NMAX = N

N = 0

DO 180 KK = NL, KU, 4

LCTR = LCTR + 1

IF (LCTR .LT. 50) GO TO 130

LCTR = 0

WHITE (5, 5080)

5080 F0WMAT(IHYTE PT BIAS EXP#

1, LOG(CURRENT) DELTA_LOG ADJ_BIAS DELTA_BIAS)

2, TE, //)

130 CONTINUE

N = N + 1

KP = 1

IF (L (KK, EU, KL) .OR. (KK .EQ. KM) .OR. (KK .EQ. KU)) KP = 2

INTEHH(1) = BUF (KK=2)

ADC = INTEH

INTEBH(1) = HUF (KK=1)

DAC = INTEH

INTEWH(1) = HUF (KK)

BIAS(1) = INTEH

ITEMP = NAV + 1

IF (N .LT. ITEMPI) GO TO 140

ITEMP = NMAX - NAV

IF (N .GT. ITEMPI) GO TO 140

DO 420 J = 1, NAV

JJ = NAV + 1 - J

FP = F (N + JJ)

FM = F (N - JJ)

IF (IIFP .GT. 0.) *ANU. (FM .GT. 0.) GO TO 430

420 CONTINUE

GO TO 140

430 DCLUG = CUHLOG (N + JJ) - CUHLOG (N - JJ)

IF (DCLUG .EQ. 0.) GO TO 140

DAYAS = HYAS (N + JJ) - HYAS (N - JJ)

TE (N) = ABS (TSCALE * DBYAS / DCLUG)

WHITE (5, 5095) KK, N, HIAS(1), EXPNR(1), PEAK(KP),

1, DAC, ADC, F (N), CUHLOG (N), DCLUG, BYAS(N), UBYAS, TE (N)

5095 F0WMAT (1, 214, 15, 05, A, 215, 1P6E13.5)

140 CONTINUE

WHITE (5, 5025) KK, N, BIAS(1), EXPNR(1), PEAK(KP),

1, DAC, ADC, F (N), CUHLOG (N), BYAS(N)

5025 F0WMAT (1, 214, 15, 05, A, 215, 1P2E13.5, 13X, E13.5)

180 CONTINUE

IF (IPLT .EQ. 0) GO TO 200

IF (15* .NE. 0) CALL CALCMP (112, 0, 0, 0)

15W = 1

DHAW AXED

2, CALL PLCH (CUHLOG, BYAS, NMID, NMAX)

3, CALL PLTEM (TE, BYAS, NMID, NMAX)

4, C LET INK DAY

5, CALL CALCMP (0, 0, 0, 0)

6, 200 CONTINUE

7, GO TO 5

8, C 10 CONTINUE

9, 1, WHITE (5, 5110) KHEC

2, 5110 F0WMAT (1, TAPE HEAD-FRONT, HFCONT) NO. 15

```

34 CONTINUE
      WRITE (5, 5130) NB, KREC, HDW
5130 FORMAT(1T1, "HECUHD SHORT BY", 10, 10X, "RECORD NO.", 15/
     1, '0', 72A1)
      GO TO 300
310 CONTINUE
      WRITE (5, 5110) KREC
      GO TO 5
330 CONTINUE
      WRITE (5, 5330) NB, KREC, HDW
5330 FORMAT(1T1, "HECUHD SHORT BY", 10, 10X, "RECORD NO.", 15/
     1, '1', 3204)
      GO TO 5
      PROCESSED MAXREC RECORDS
      WRITE (5, 5888)
5888 FORMAT(1T1, "COMPLETED RECHDS SPECIFIED")
      STOP
      EOF
      END
      999 CONTINUE
      WRITE (5, 5999)
5999 FORMAT(1T1, "END-OF-FILE!")
      STOP
      EOF
      END
      SUBROUTINE PLCUR (CURLOG, BYAS, NMID, NMAX)
      REAL*4 CURLOG(500), BYAS(500)
      DATA C / 1.25 /
      DATA D / J. /
      DATA ISYMDN / 91/
      DATA ISYMP / 95/
      DATA A / 1.5 /
      DATA B / 10.5 /
      DO 100 I = 1, NMAX
      C TRANSFORM ALL BYAS AS MAY NEED IN SUBRTN PLTEM
      BYAS(I) = C * BYAS(I) + D
100 IF (BYAS(I) .LT. 1.75) .OR. (BYAS(I) .GT. 6.75) GO TO 100
      IF (CURLOG(I) .GT. -4.) .OR. (CURLOG(I) .LT. -9.) GO TO 100
      CURLOG(I) = A * CURLOG(I) + B
      ISYM = ISYMDN
      IF (I .GT. NMID) ISYM = ISYMP
      CALL SYMBOL (BYAS(I), CURLOG(I), 0.05, ISYM, 0., -1)
100 CONTINUE
      END
      RETURN
      END
      SUBROUTINE PLTEM (TE, BYAS, NMID, NMAX)
      REAL*4 TE(500), BYAS(500)
      DATA ISYMDN / 93 /
      DATA ISYMP / 94 /
      DATA A / 3.0 /
      DATA B / -3.0 /
      DATA CUT / 6.5 /
      C CUT MUST CHANGE IF C, D IN SUBRTN PLCUR CHANGE
      2 C BYAS HAS BEEN TRANSFORMED BY IMMEDIATELY PREVIOUS CALL PLCUR
      CC 100 I = 1, NMAX
      IF (BYAS(I) .GT. CUT) GO TO 100
      IF ((TE(I) .GT. 3.0000E4) .OR. (TE(I) .LT. 100.)) GO TO 100
      TE(I) = A + ALUG10 (TE(I)) * B
      ISYM = ISYMDN
      IF ((I .GT. NMID) ISYM = ISYMP
      CALL SYMBOL (BYAS(I), TE(I), 0.05, ISYM, 0., -1)
100 CONTINUE
      RETURN
      END

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INTEGER*2 IDATE (3)
INTEGER*2 NCD (5)
DATA ISYM / 31 /
DATA AL / 1.75 /
DATA YB / 3. /
DATA XSCALE / 0.125 /
DATA XH / 6.75 /
DATA TSCALE / 3. /
DATA CSCALE / 1.5 /
DATA TL / 0.301030, 0.477121, 0.602060, 0.698970, 0.778151,
     0.845098, 0.903090, 0.954243 /
C
C   FPN = -1.
C   CALL NUMBER (XL=0.100, YH=0.500, 0.250, FPN, 0.. -1)
C   DUPLICATE TO ENSURE INK START
C   CALL NUMBER (XL=0.100, YB=0.500, 0.250, FPN, 0.. -1)
K = 0
CALL CALCMP (XL, YB, 0, 1)
DO 22 I = 1..4
DO 18 J = 1, 9
K = K + 1
X = AL + K * XSCALE
CALL SYMBOL (X, YB, 0.14, ISYM, 0.. -2)
18 CONTINUE
K = K + 1
X = AL + K * XSCALE
CALL SYMBOL (X, YB, 0.28, ISYM, 0.. -2)
FPN = 1 - 1
CALL NUMBER (XH=0.100, YB=0.500, 0.250, FPN, 0.. -1)
CALL CALCMP (XH, YB, 0, 1)
22 CONTINUE
FPN = 10.
CALL NUMBER (XH=0.25, YB, 0.25, FPN, 0.. -1)
FPN = 2.
CALL NUMBER (999., YB=0.125, 0.15, FPN, 0.. -1)
CALL CALCMP (XH, YB, 0, 1)
DO 28 I = 1, 3
JJ = 8
IF (I * EQ. 3) JU = 2
DO 26 J = 1, JJ
Y = YB + TSCALE * (TL(J) * I - 1)
CALL SYMBOL (XH, Y, 0.1, ISYM, 50.. -2)
26 CONTINUE
IF (I * EQ. 3) GO TO 28
Y = YB + 1 * TSCALE
CALL SYMBOL (XH, Y, 0.28, ISYM, 90.. -2)
FPN = 10.
CALL NUMBER (XH=0.25, Y, 0.25, FPN, 0.. -1)
CALL CALCMP (XH, Y, 0, 1)
FPN = 1 * 2
CALL NUMBER (999., Y=0.125, 0.15, FPN, 0.. -1)
CALL CSCALE (XL, Y, 0.14, ISYM, 90.. -2)
28 CONTINUE
YSV = Y
FPN = -9.
11 CALL NUMBER (XL=0.75, YH, 0.25, FPN, 0.. -1)
12 CALL CALCMP (XL, YB, 0, 1)
DO 36 I = 1..5
DO 36 J = 1..d
7 Y = YB + CSCALE * (TL(J) * I - 1)
CALL SYMBOL (XL, Y, 0.14, ISYM, 90.. -2)
36 CONTINUE
Y = YB + 1 * CSCALE
CALL SYMBOL (XL, Y, 0.28, ISYM, 90.. -2)
FPN = 1 - 9
CALL NUMBER (XL=0.75, Y=0.25, FPN, 0.. -1)

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OF POOR QUALITY.

33 CONTINUE
K = 0
DO 42 I = 1, 4
DO 48 J = 1, 9
K = K + 1
X = XL * K * XSCALE
CALL SYMBOL (X, Y, 0.14, ISYM, 0., -2)

48 CONTINUE
K = K + 1
X = XL * K * XSCALE
CALL SYMBOL (X, Y, 0.28, ISYM, 0., -2)

42 CONTINUE

CALL CALCP (XH, YS, 1, 1)
CALL SYMBOL (XL-1.20, YH+3.0, 0.30, 'LOG 1', 90., 5)
CALL SYMBOL (XL-1.9, YH-1.0, 0.25, 'BIAS', 0., 4)
CALL SYMBOL (XH-1.35, YB+0.5, 0.30, 'GENERALIZED TEMPERATURE',
1 90., 23)
CALL SYMBOL (XL, YH-1.50, 0.250, IDATE(1), 0., 2)
CALL SYMBOL (949., YH-1.50, 0.250, '/', 0., 1)
CALL SYMBOL (999., YH-1.50, 0.250, IDATE(2), 0., 2)
CALL SYMBOL (949., YB-1.50, 0.250, '/', 0., 1)
CALL SYMBOL (999., YB-1.50, 0.250, IDATE(3), 0., 2)
E*CODE (10, 7000, NCD) NEXP
7000 FORMAT (E9.16)
CALL SYMBOL (XH-2.50, YB-1.50, 0.250, NCD, 0., 16)
RETURN
END